New Physics after the LHC
Now and Future

Shufang Su • U. of Arizona

Next Step in the Energy Frontier - Hadron Collider

August 28, Fermilab

Outline

Where is the physics beyond the SM?

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- What did we learn from LHC 7/8 TeV (20 fb^{-1}) ?

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$\longrightarrow$ E_{cm}

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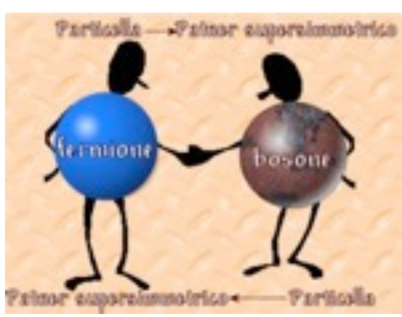
- top partners (naturalness)



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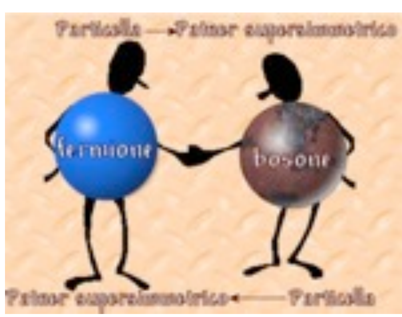
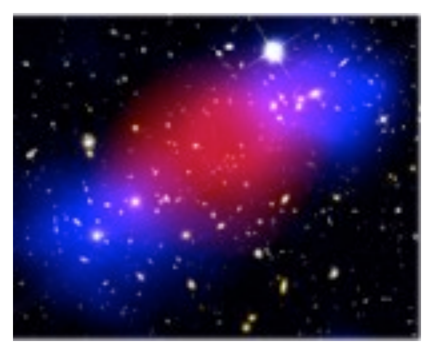


- dark matter



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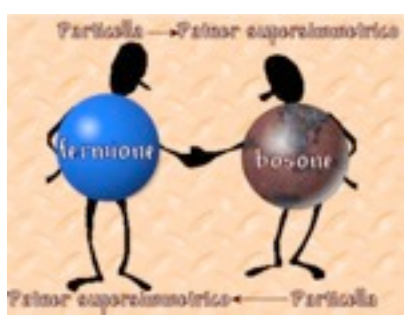

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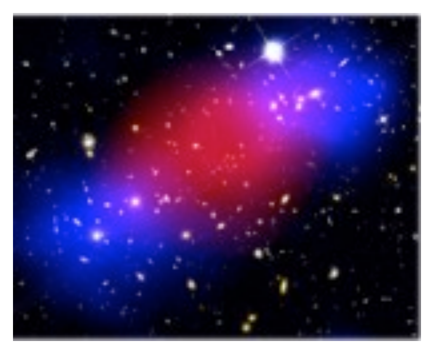
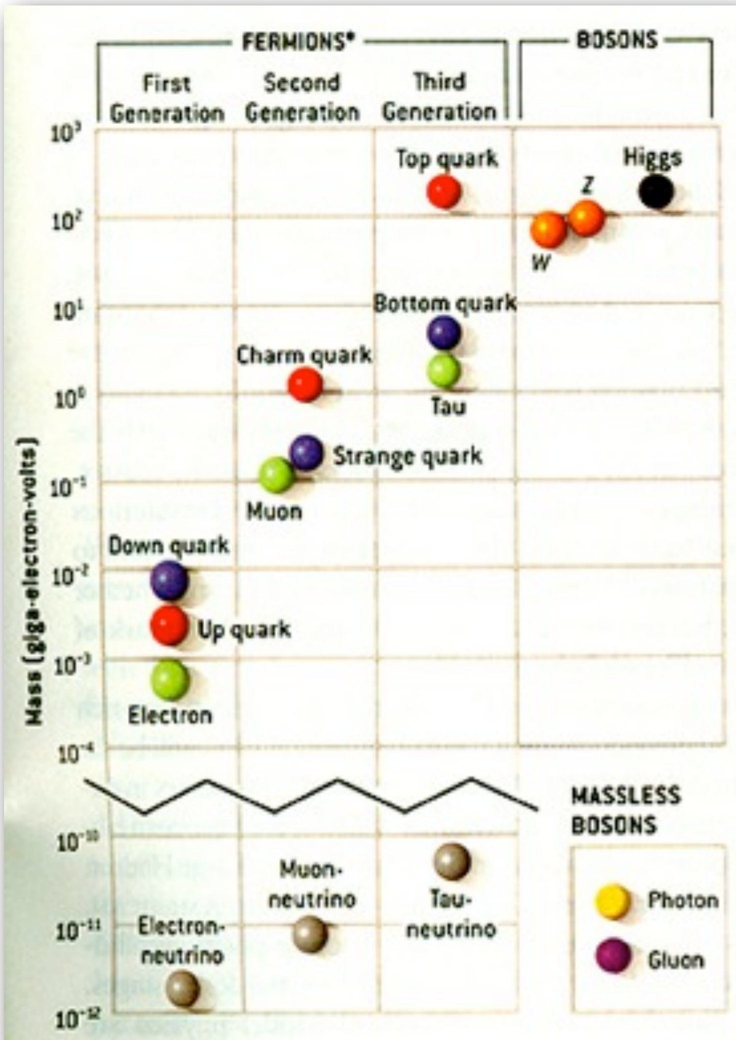


- other BSM

Standard Model

Image credit: Gordon Kane, Scientific American, June 2003.



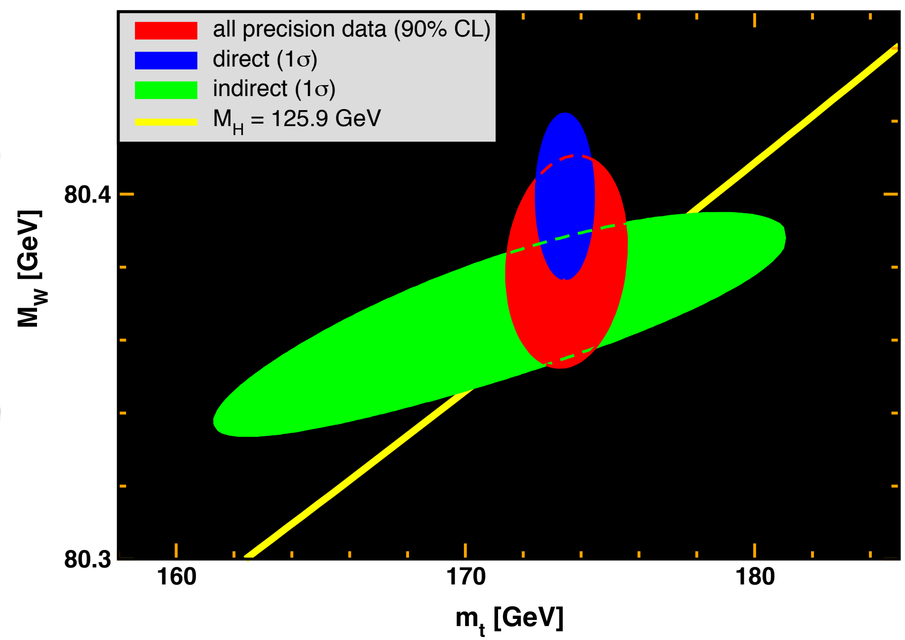
TeV

GeV

MeV

eV

Erler, Su (2013)



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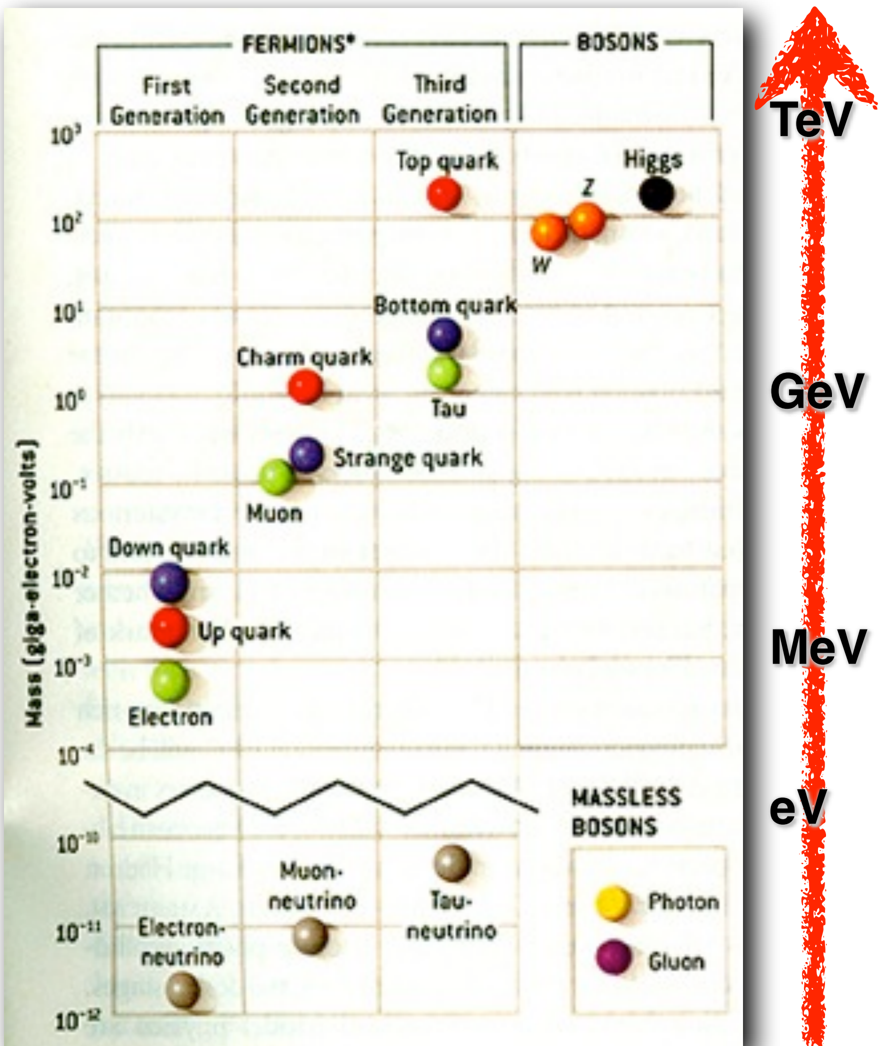

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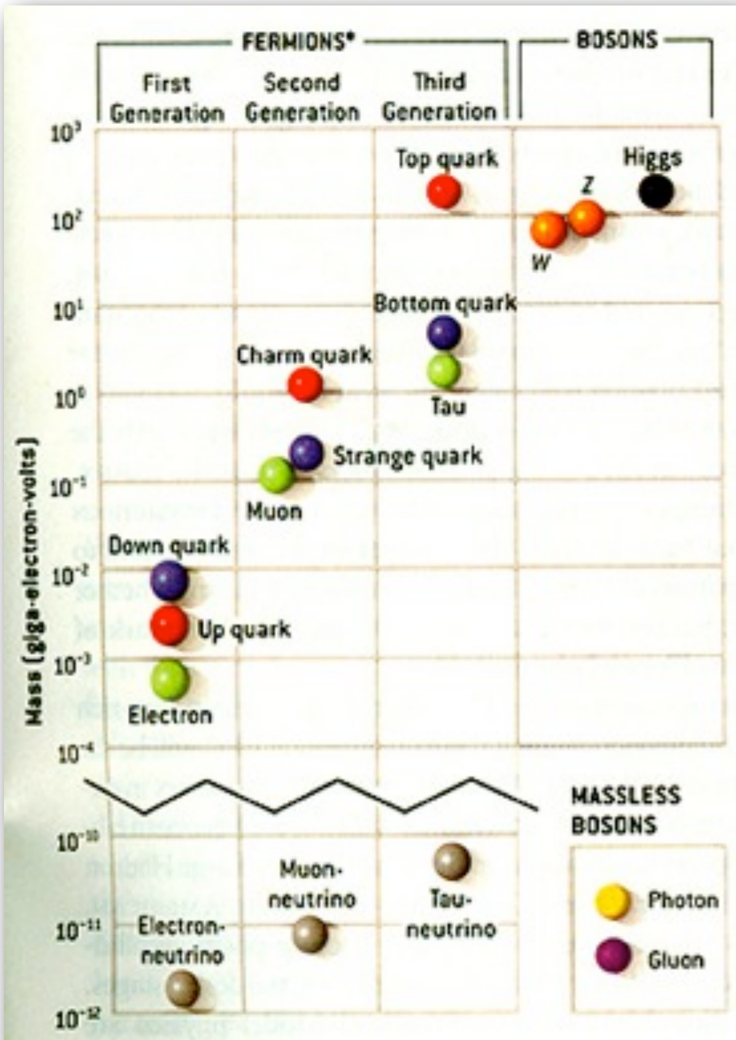

- **SM complete**

  valid up to Planck scale

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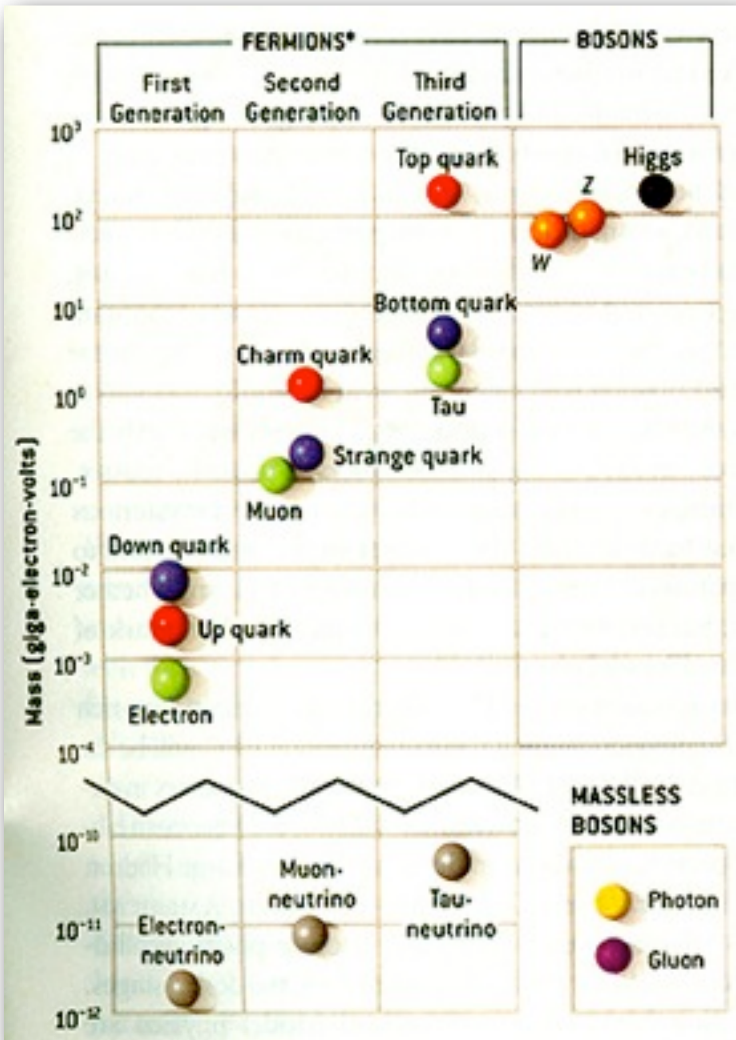

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- Big questions

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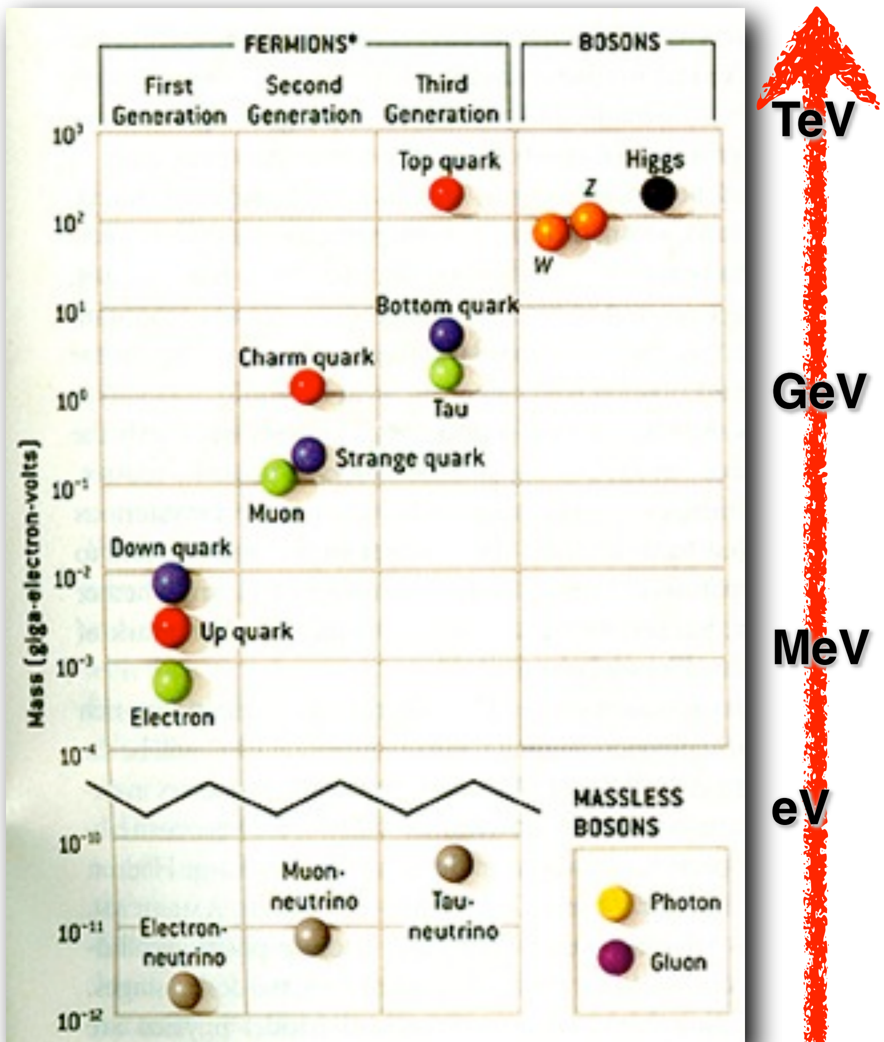

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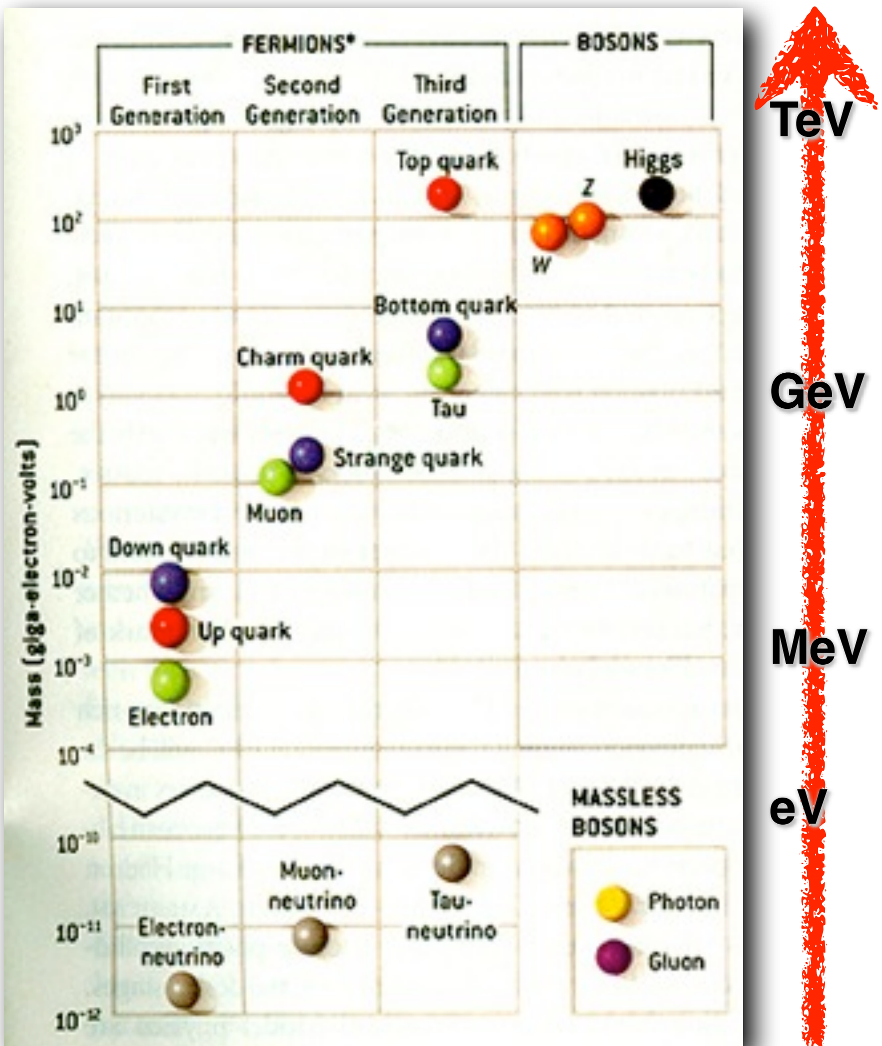

- SM complete

  valid up to Planck scale
- Big questions
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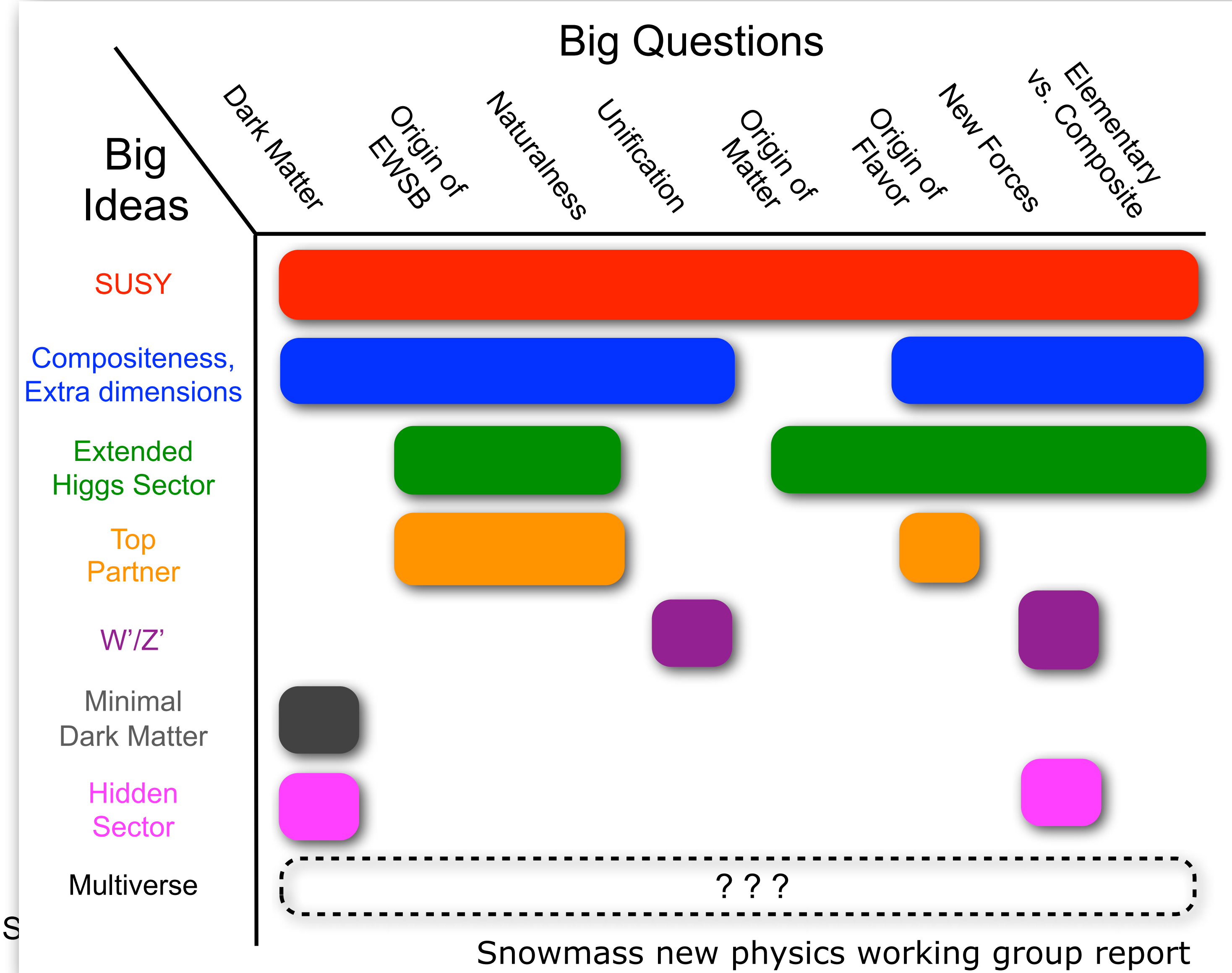
- unexpected...

New Physics beyond the SM



S. S

What did we learn from LHC 7/8 TeV ?

A Light Higgs is Puzzling...

- Light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV
  - ➡ spin 0, a new kind of fundamental particle
  - ➡ Nothing protects its mass ⇒ New physics beyond the SM

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Then What? Still a lot of hard, but fun work to do!

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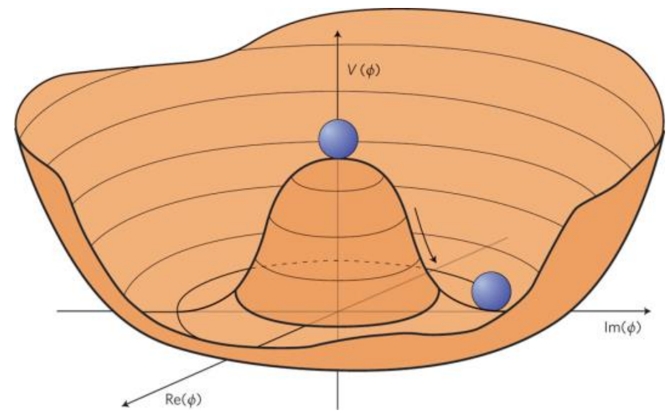

$$V(\phi) = \frac{1}{2}\mu_h^2\phi^2 + \frac{\lambda}{4}\phi^4$$

$$\langle\phi\rangle \equiv v \neq 0 \quad \rightarrow \quad m_W = g_W\frac{v}{2}$$

$$M_H^2 = -2\mu^2 = 2\lambda v^2$$

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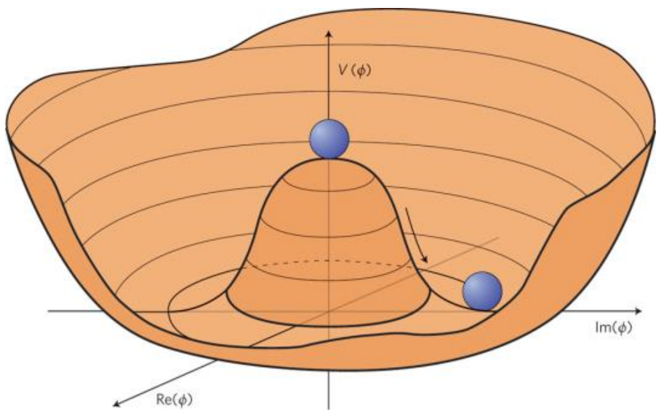
A new force of nature? $\lambda \sim 1/8$



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At the verge of uncovering a deep theory

- λ determined by guage couplings?
  e.g., SUSY, $\lambda = (g_1^2+g_2^2)/8$ ...
- or dynamically generated by a new strong force?
  e.g., composite Higgs, Higgsless, extra dimensions,...

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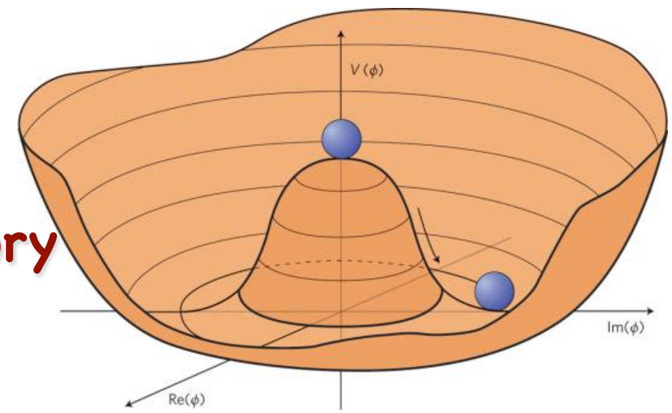

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Then What? **experimentally...**

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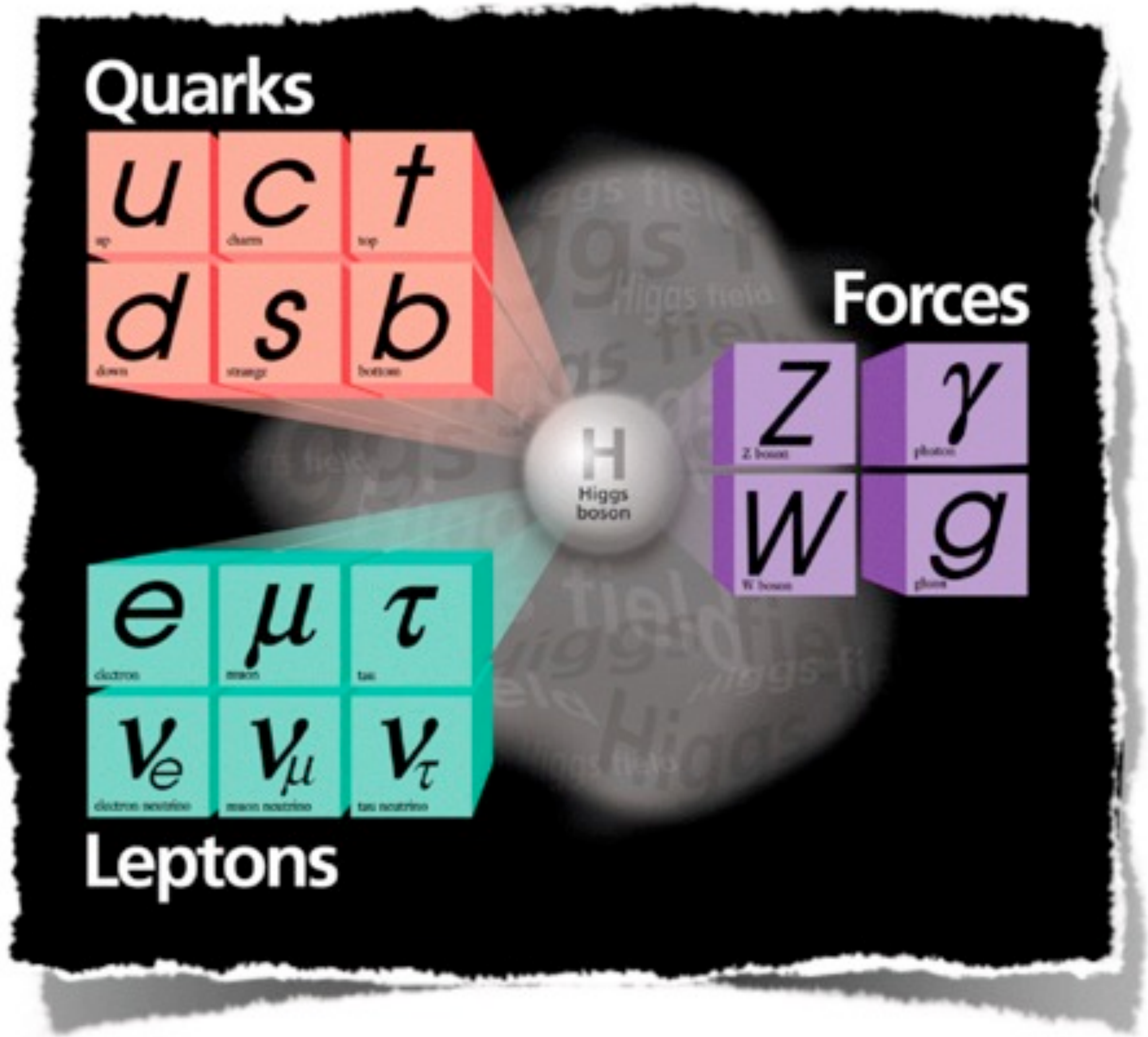
Quarks
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Higgs boson
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ν_τ
Leptons


Quarks
Forces
Higgs

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...


Quarks
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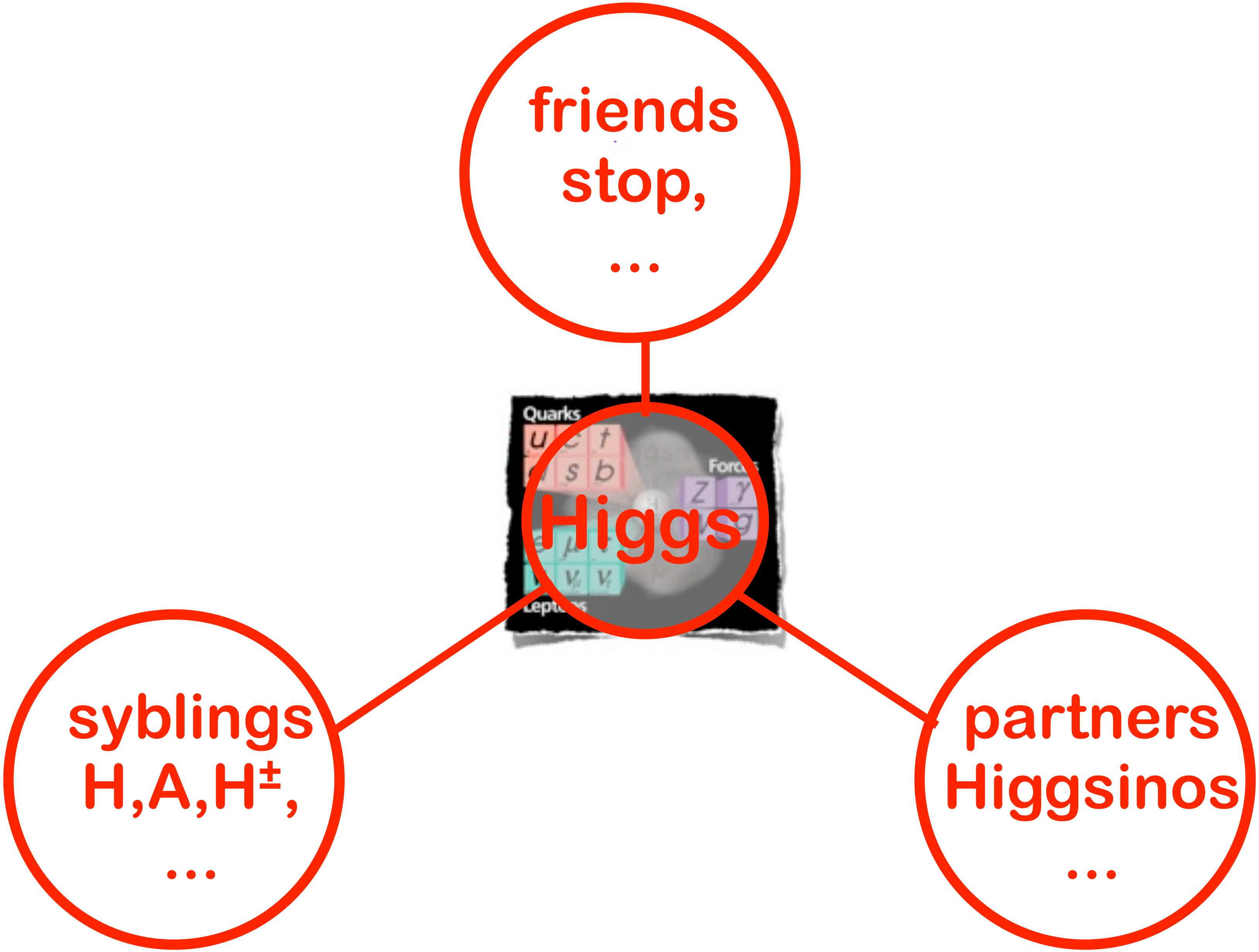
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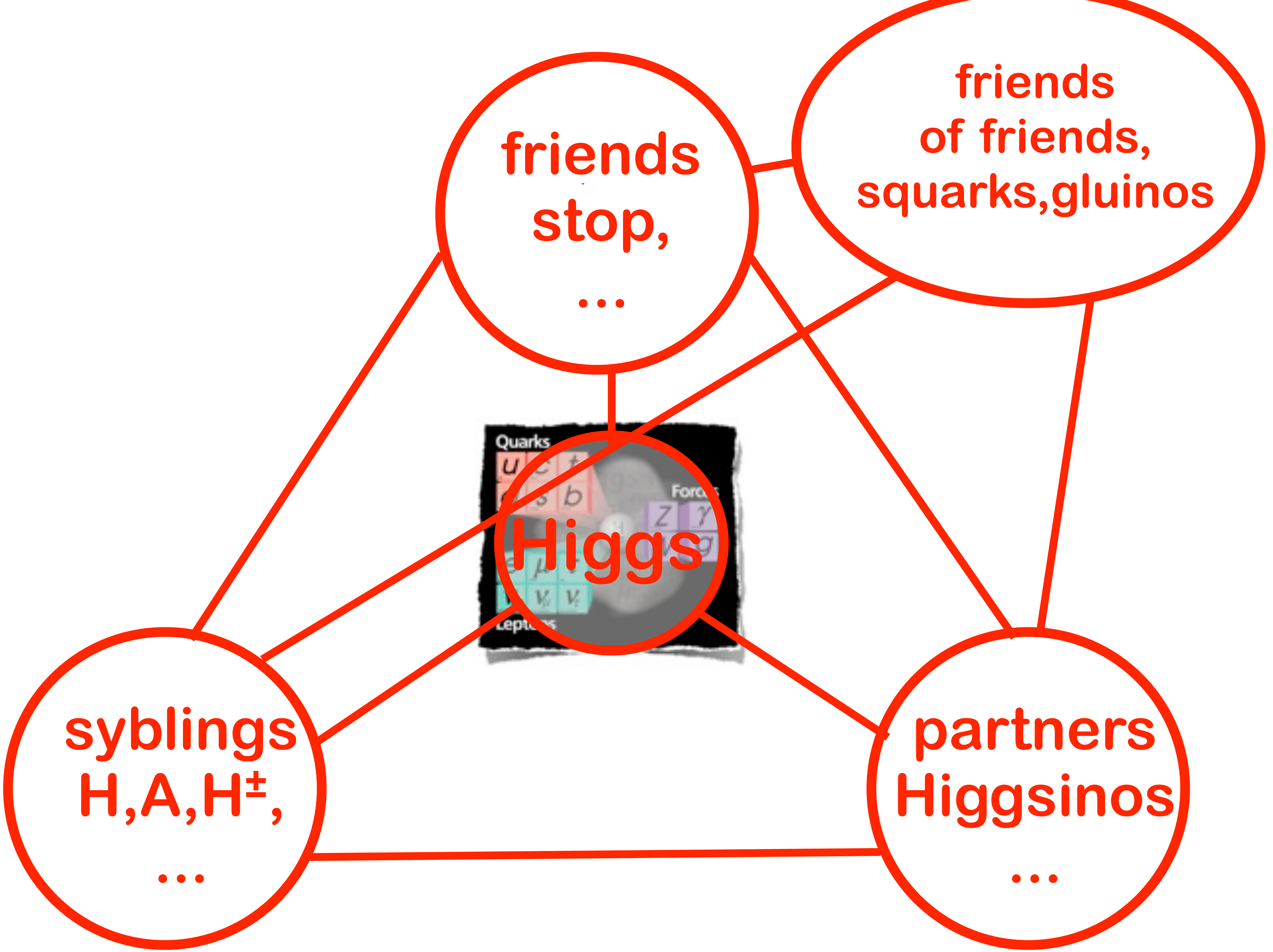
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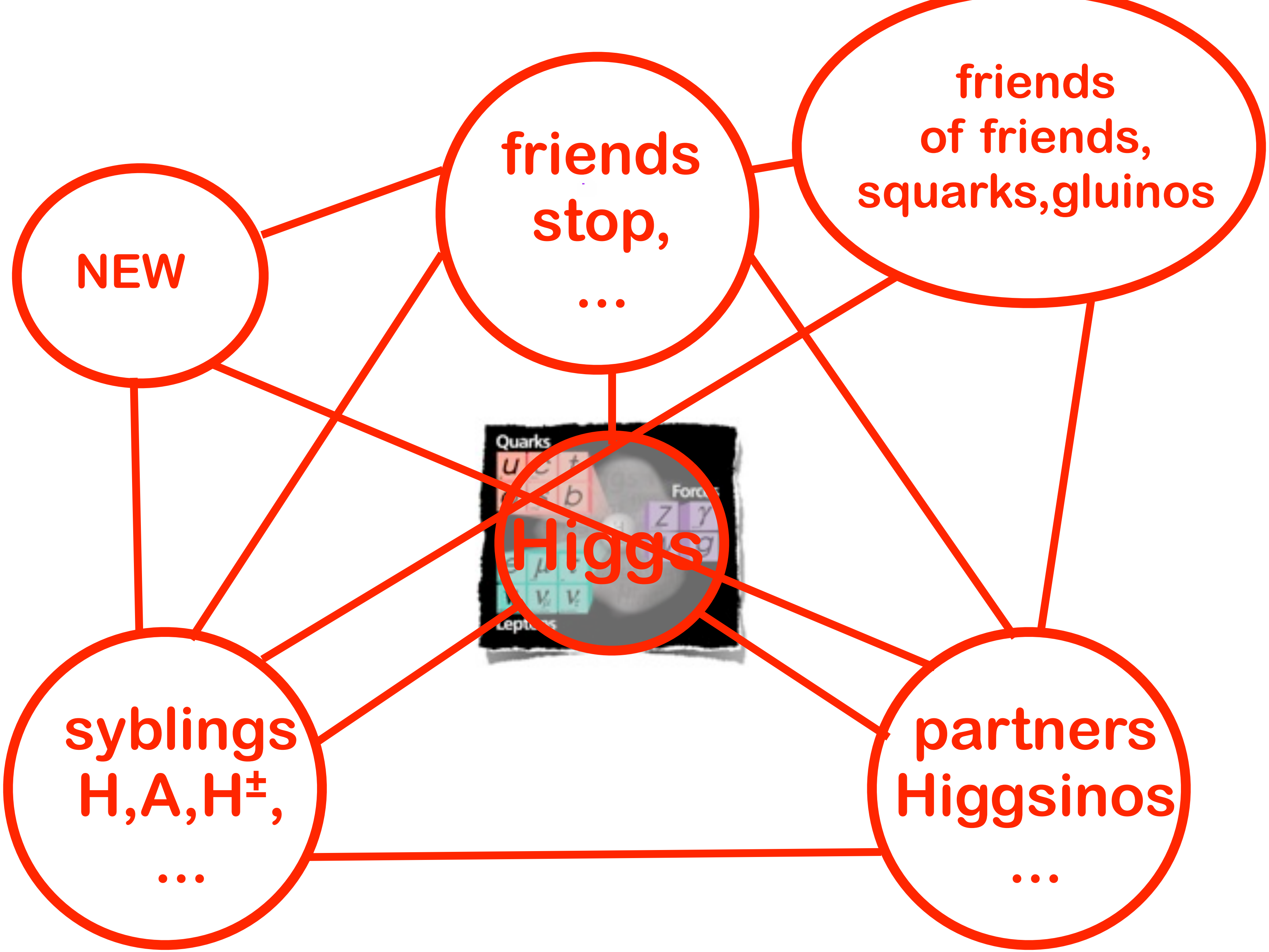
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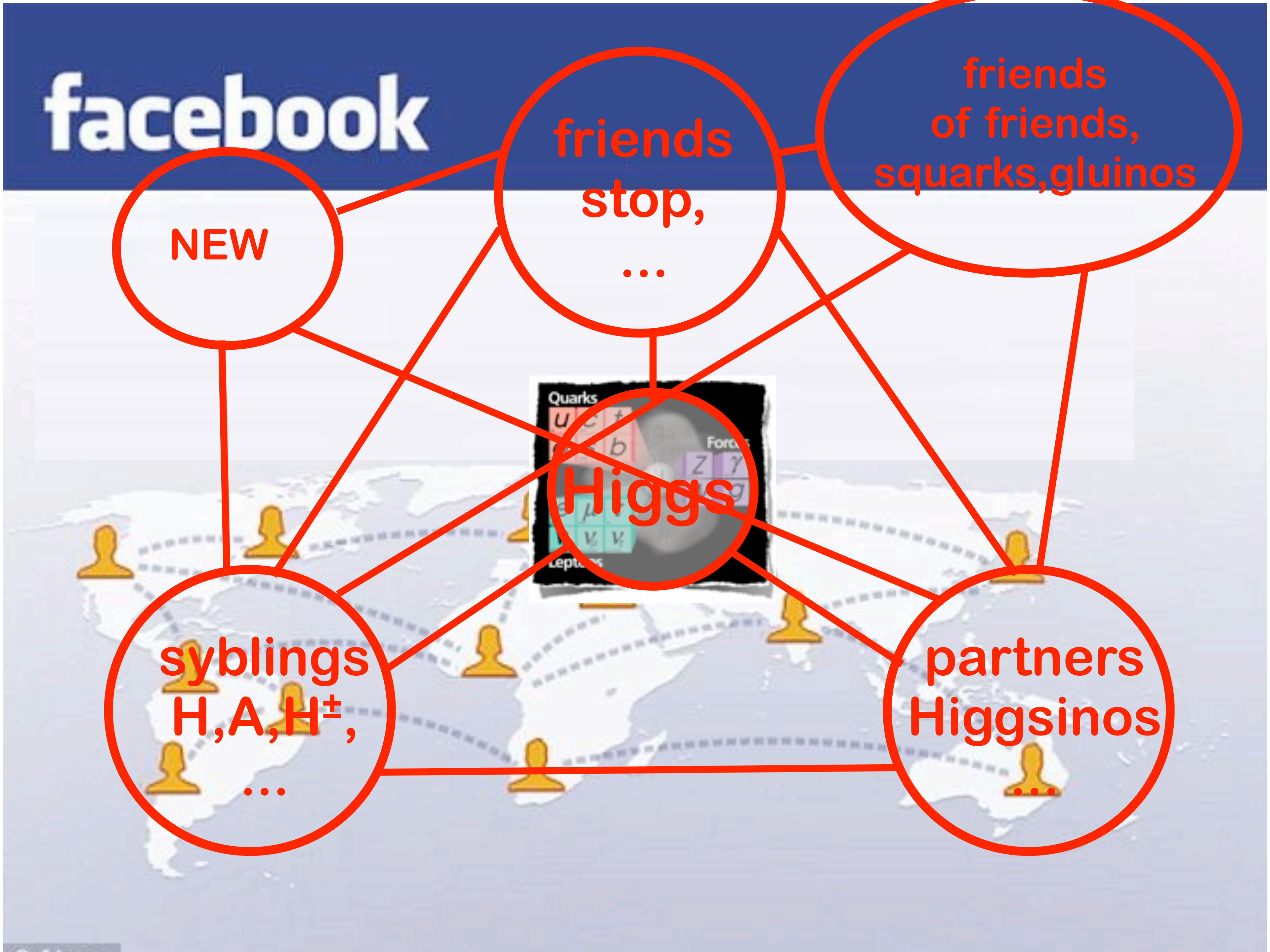
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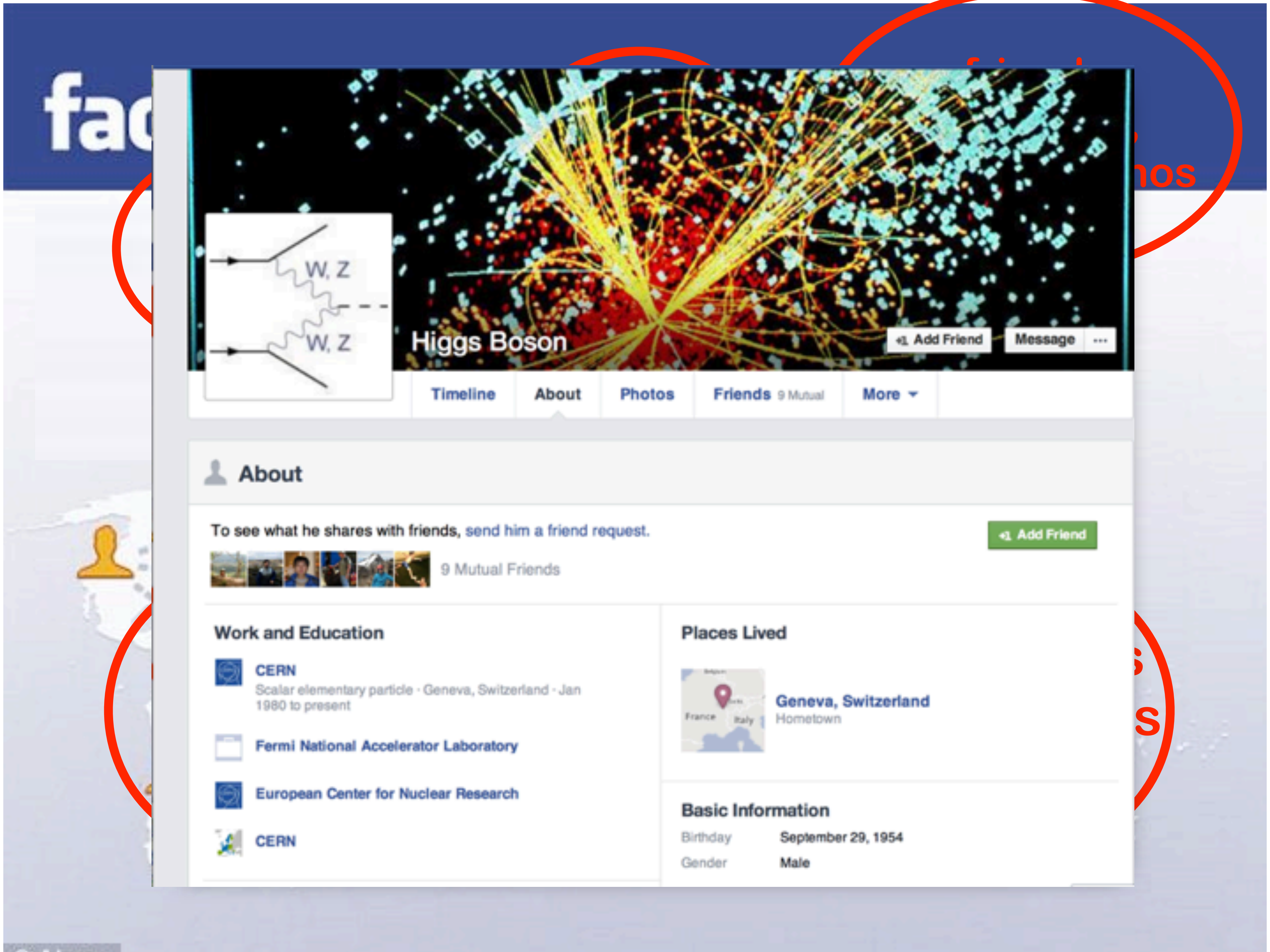
W, Z
W, Z
Higgs Boson
Add Friend
Message
Timeline
About
Photos
Friends 9 Mutual
More
About
To see what he shares with friends, send him a friend request.
Add Friend
9 Mutual Friends
Work and Education
CERN
Scalar elementary particle · Geneva, Switzerland · Jan 1980 to present
Fermi National Accelerator Laboratory
European Center for Nuclear Research
CERN
Places Lived
France
Italy
Geneva, Switzerland
Hometown
Basic Information
Birthday September 29, 1954
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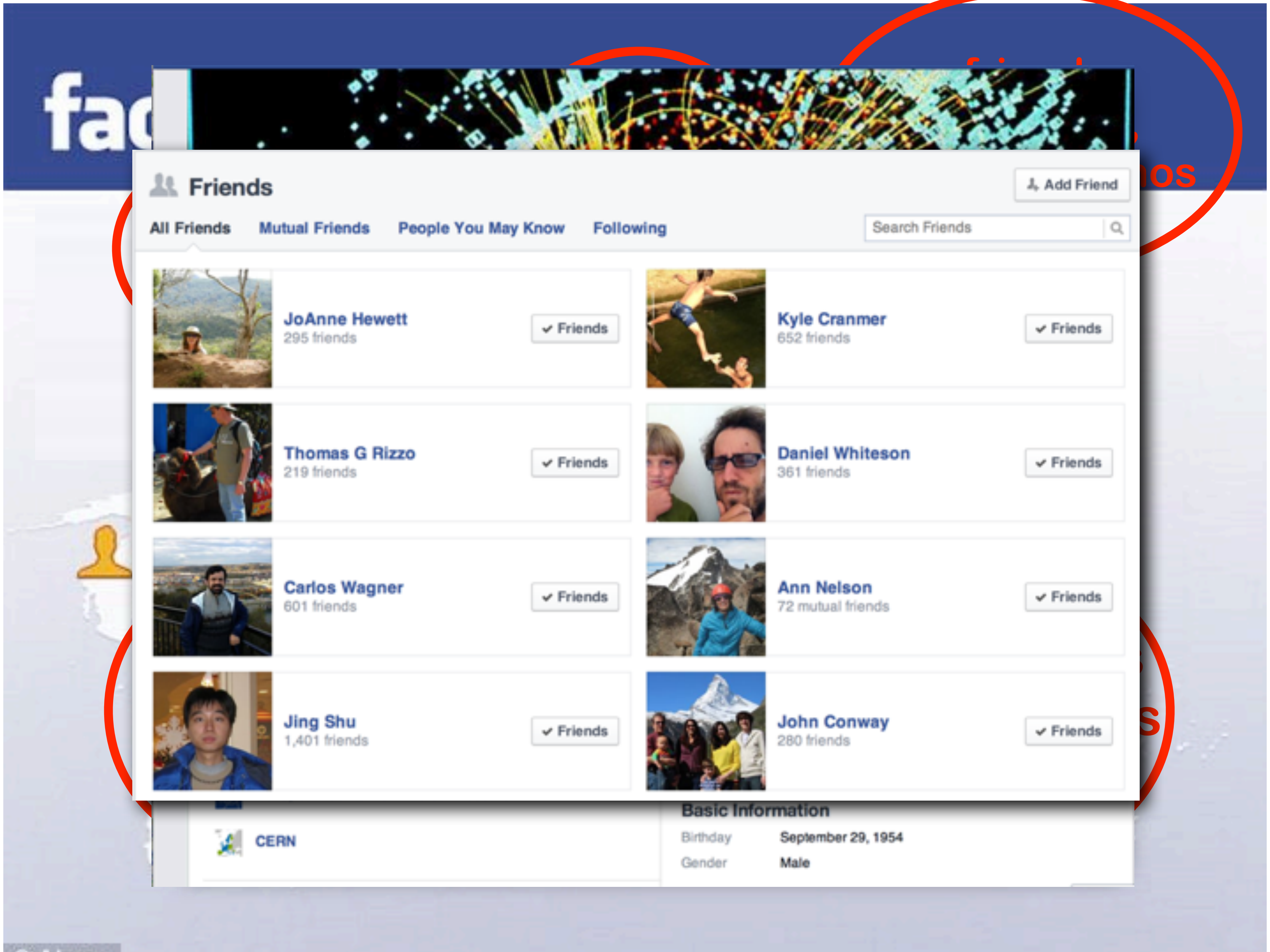
Friends
Add Friend
All Friends
Mutual Friends
People You May Know
Following
Search Friends
JoAnne Hewett
295 friends
Friends
Kyle Cranmer
652 friends
Friends
Thomas G Rizzo
219 friends
Friends
Daniel Whiteson
361 friends
Friends
Carlos Wagner
601 friends
Friends
Ann Nelson
72 mutual friends
Friends
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1,401 friends
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John Conway
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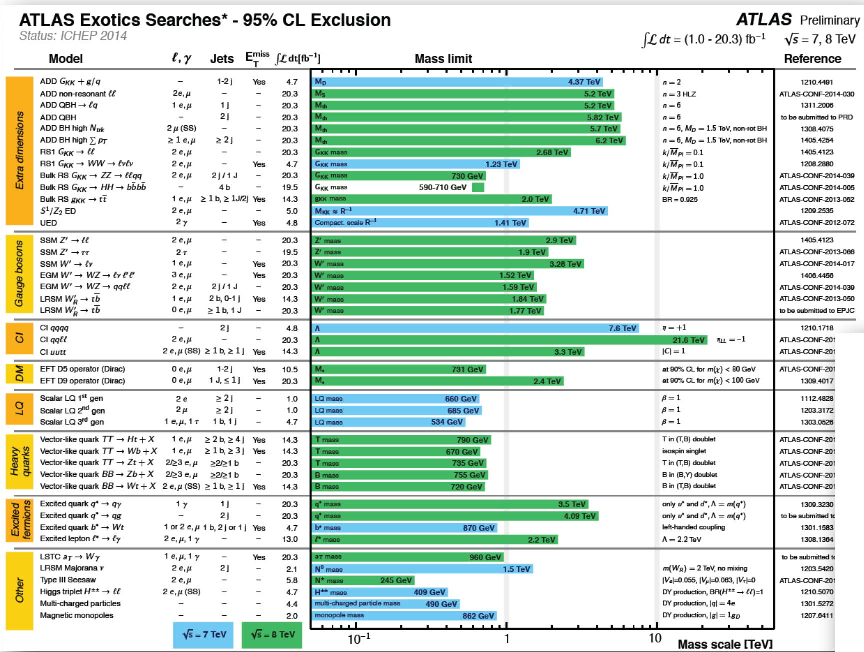
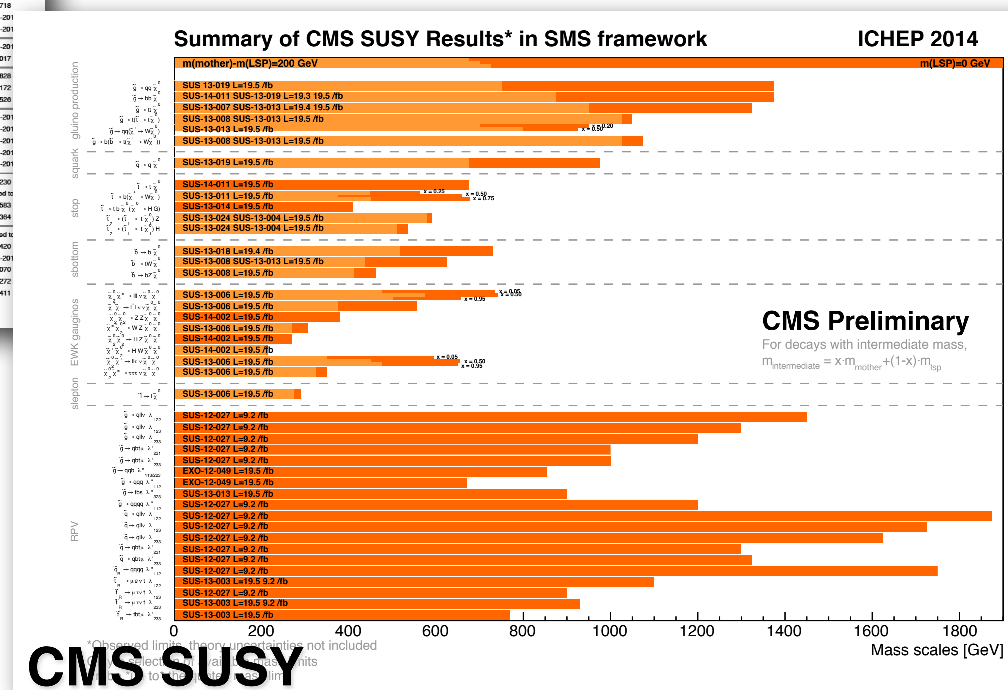


ATLAS exotic



CMS SUSY

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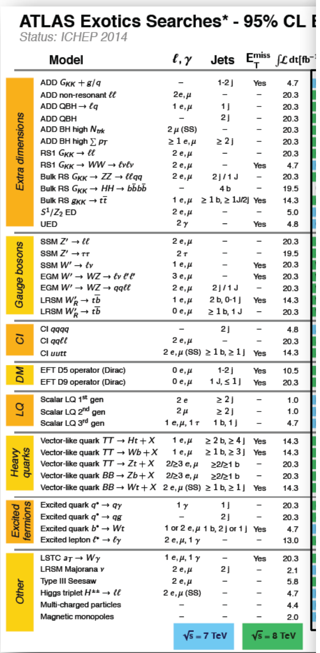

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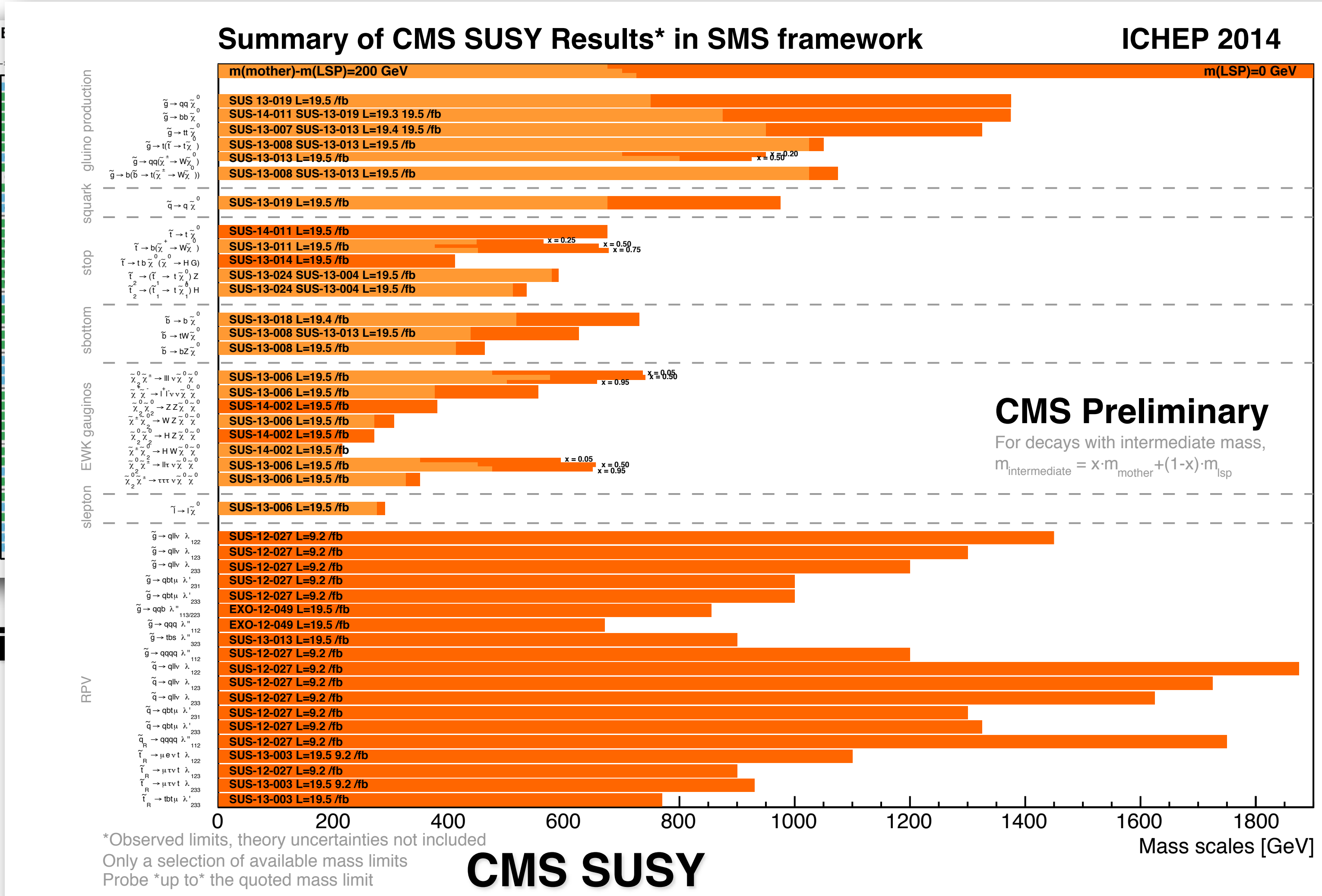

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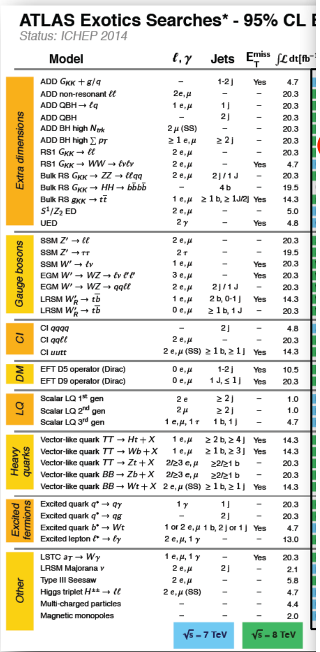

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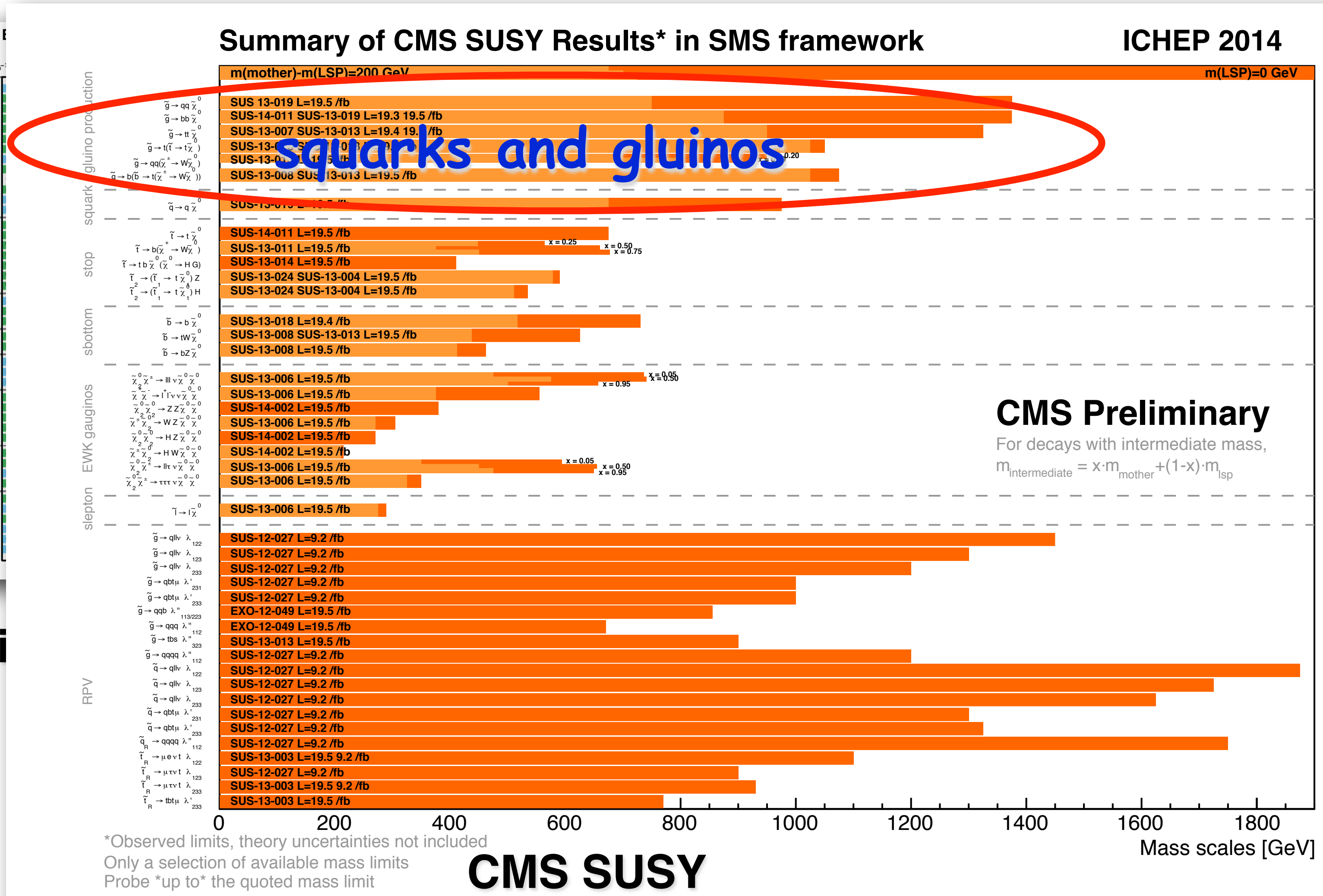

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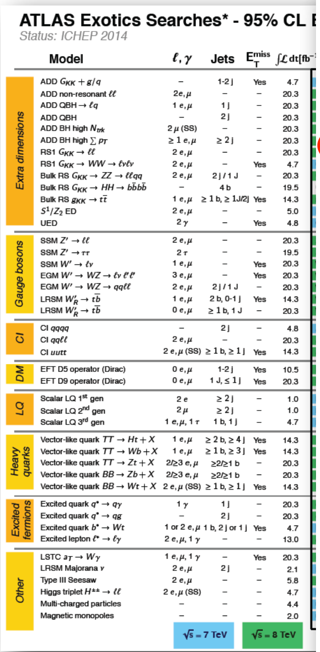

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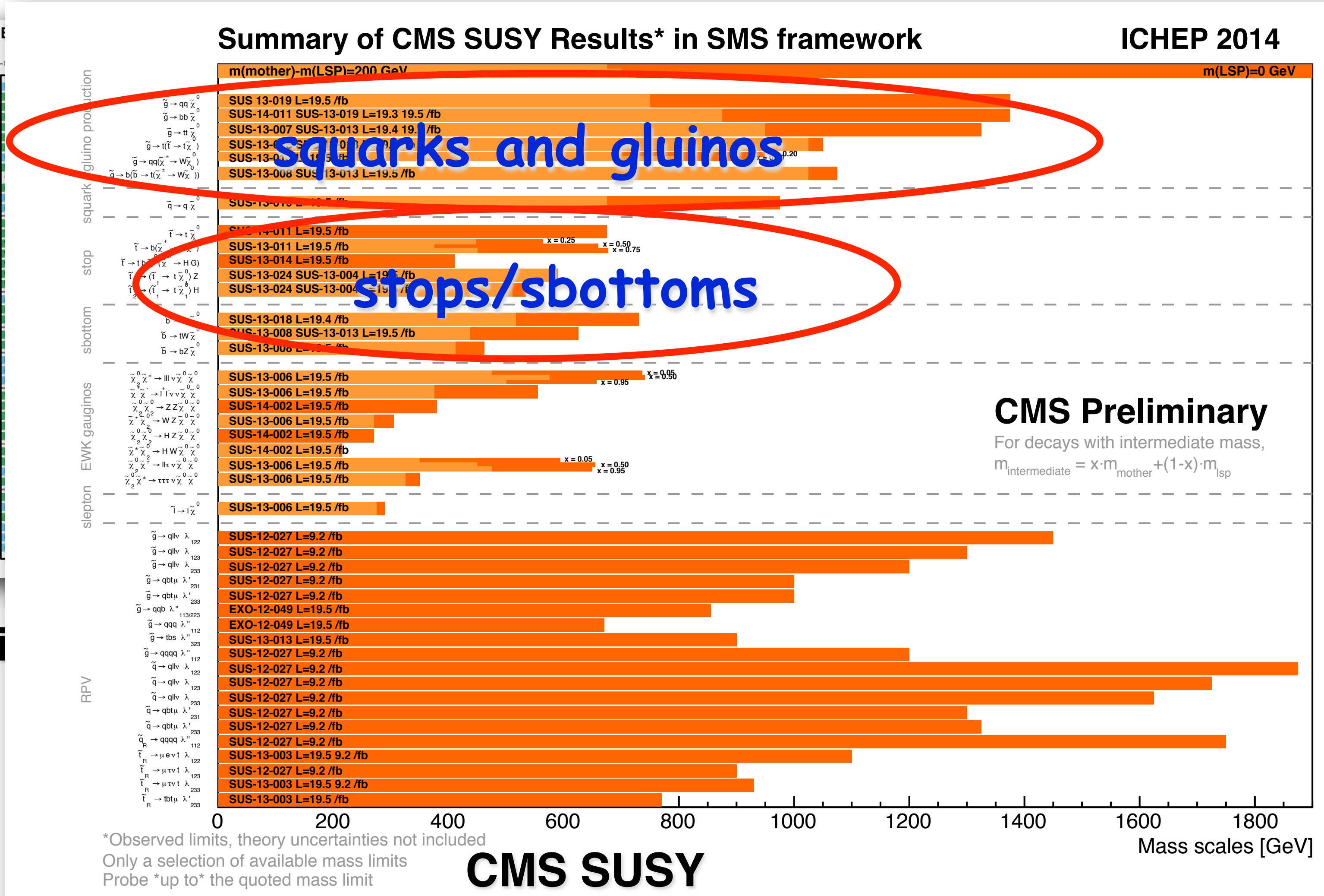

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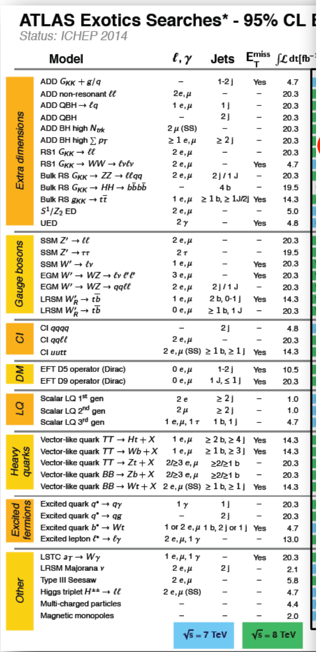

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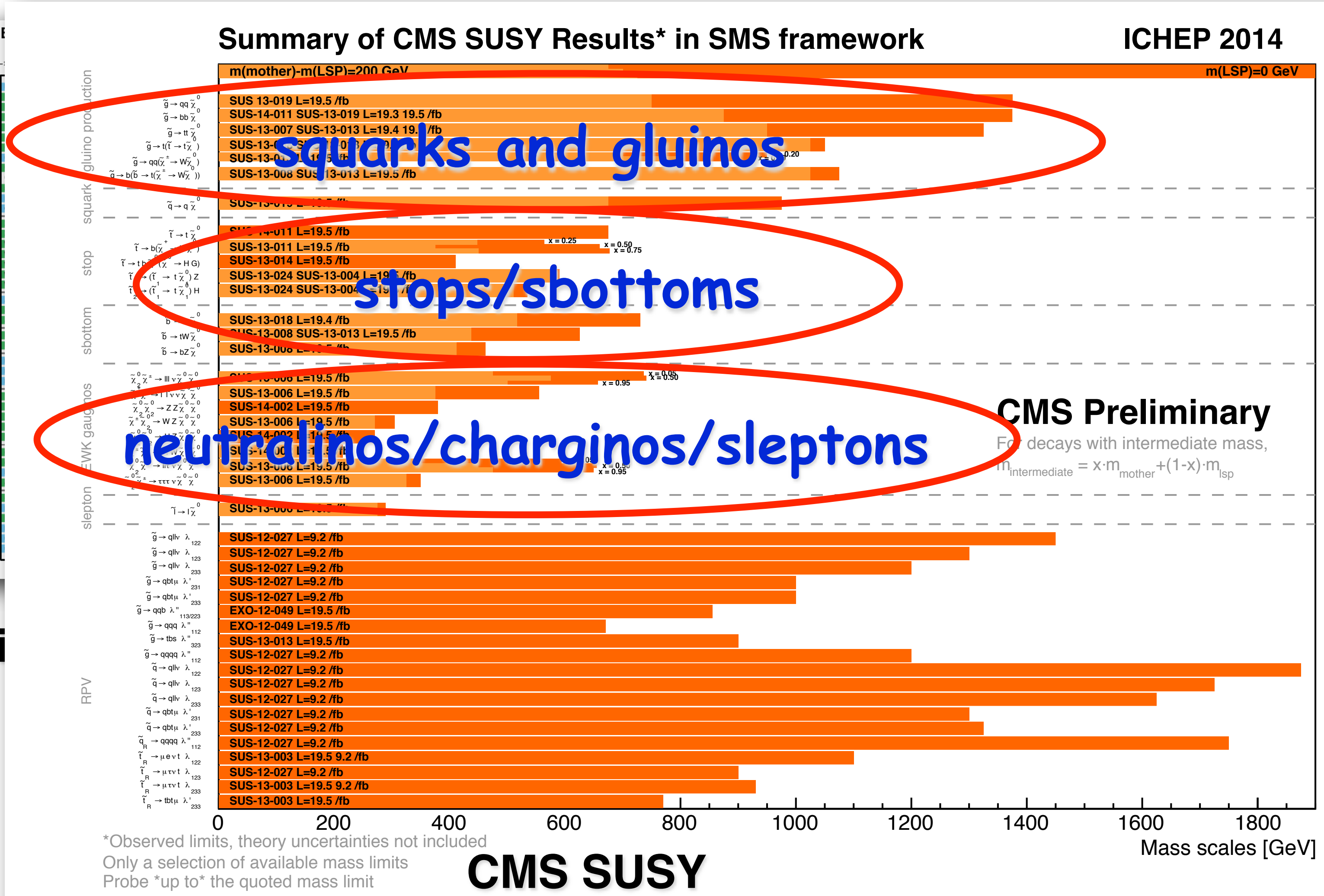

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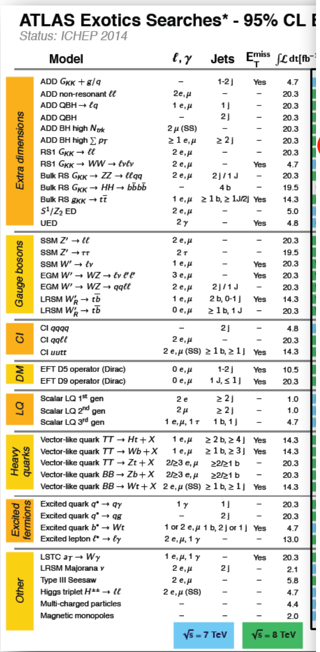

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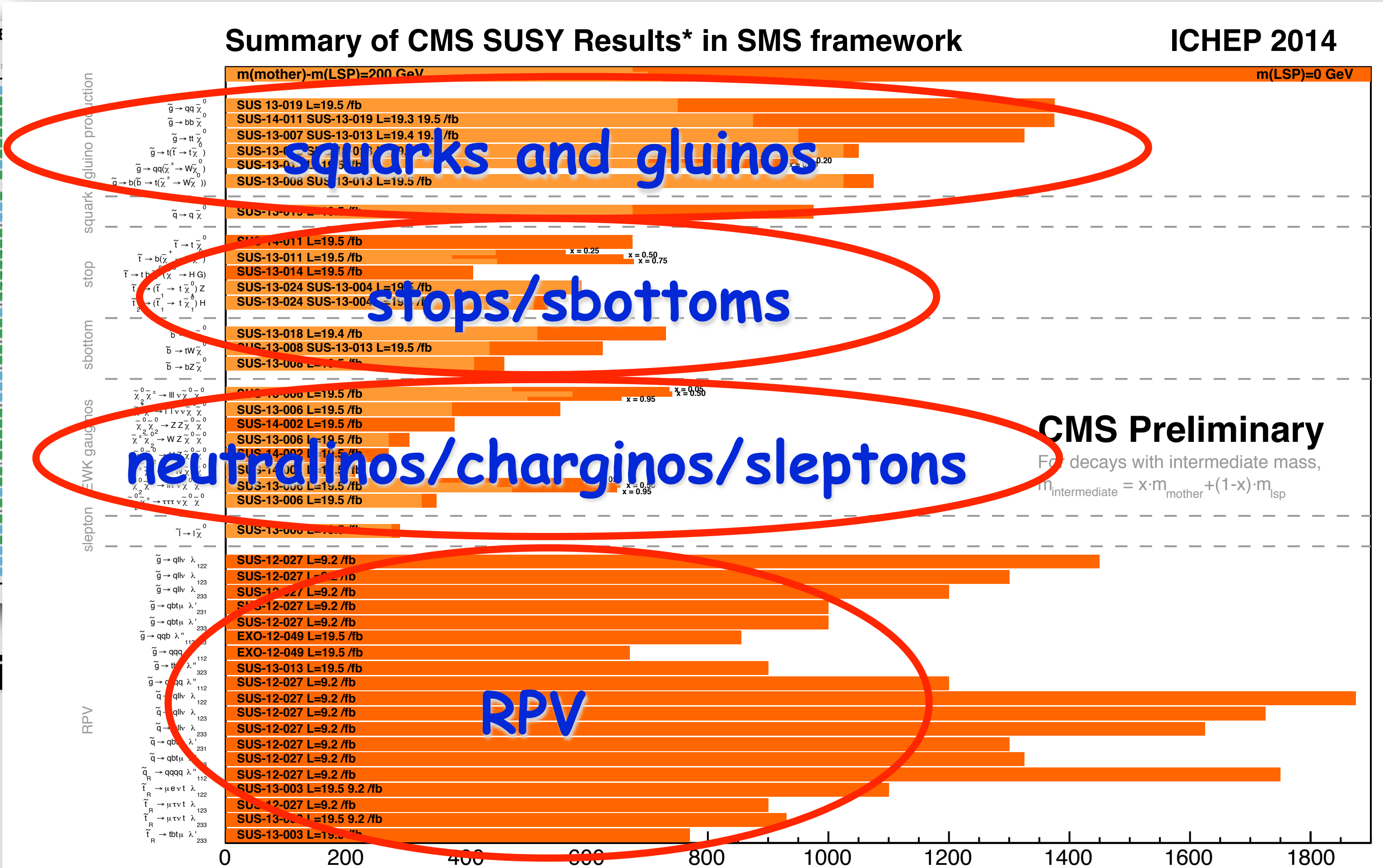

CMS SUSY

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Then What?

<u>**Where is New Physics?**</u>

larger mass? Small Coupling? Too much BG?

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  Need colliders/measurements with unprecedented accuracy

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  Need colliders/measurements with unprecedented accuracy

  (e+e- or pp with high luminosity)

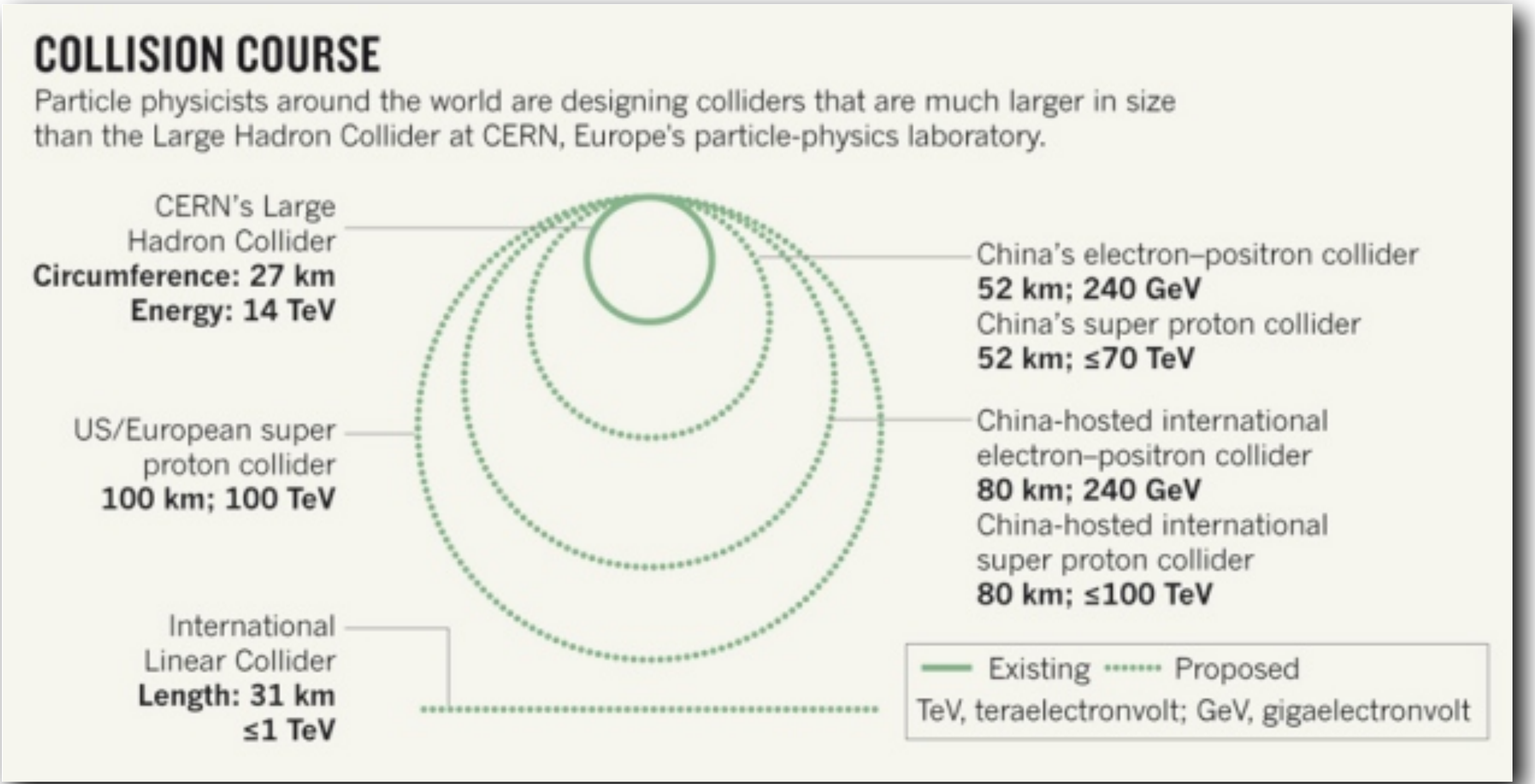
Machine Options

China plans super collider

Nature News, July

Proposals for two accelerators could see country become collider capital of the world.

Elizabeth Gibney



Physics opportunity for HL-LHC

14 TeV with 3 ab-1

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14 TeV with 3 ab-1

- EW Physics

  m_t, m_W, rare top decay, VVV/VVVV couplings, WW scattering,...
- Higgs Physics

  mass, width, CP, coupling, rare decay, self-coupling
- New heavy particles

Physics opportunity at pp machine

80 - 100 TeV

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- new particles: a few TeV - 30 TeV, beyond LHC reach
- increased rate for sub-TeV particle: increased precision wrt LHC/ILC: Z, W, top,...
- rare process in sub-TeV mass range
- Higgs and EWSB: more Higgs couplings, WW scattering, Higgs self-coupling

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- Higgs and EWSB: more Higgs couplings, WW scattering, Higgs self-coupling

SM Issues:
Parton distribution functions, Prof. Joey Huston (Michigan State University)
Top PDFs, Ahmed Ismail (ANL/UIC)

Study the SM-like Higgs

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- Deviation of SM Higgs couplings
- New coupling structures, beyond the SM
- Higgs couples to new particles

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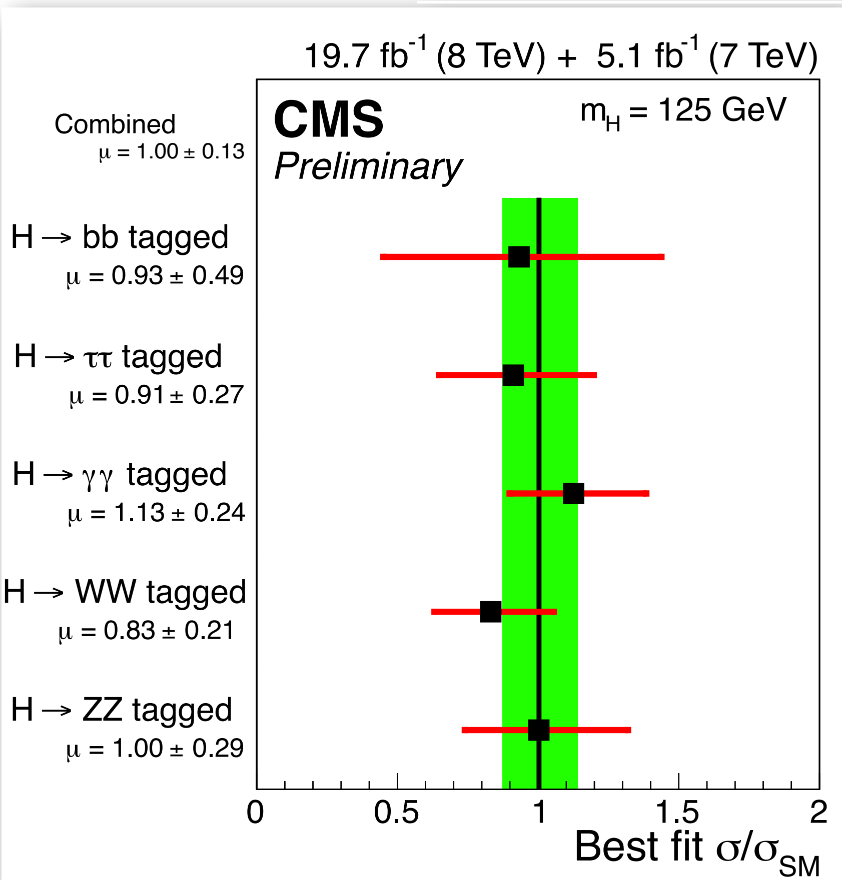
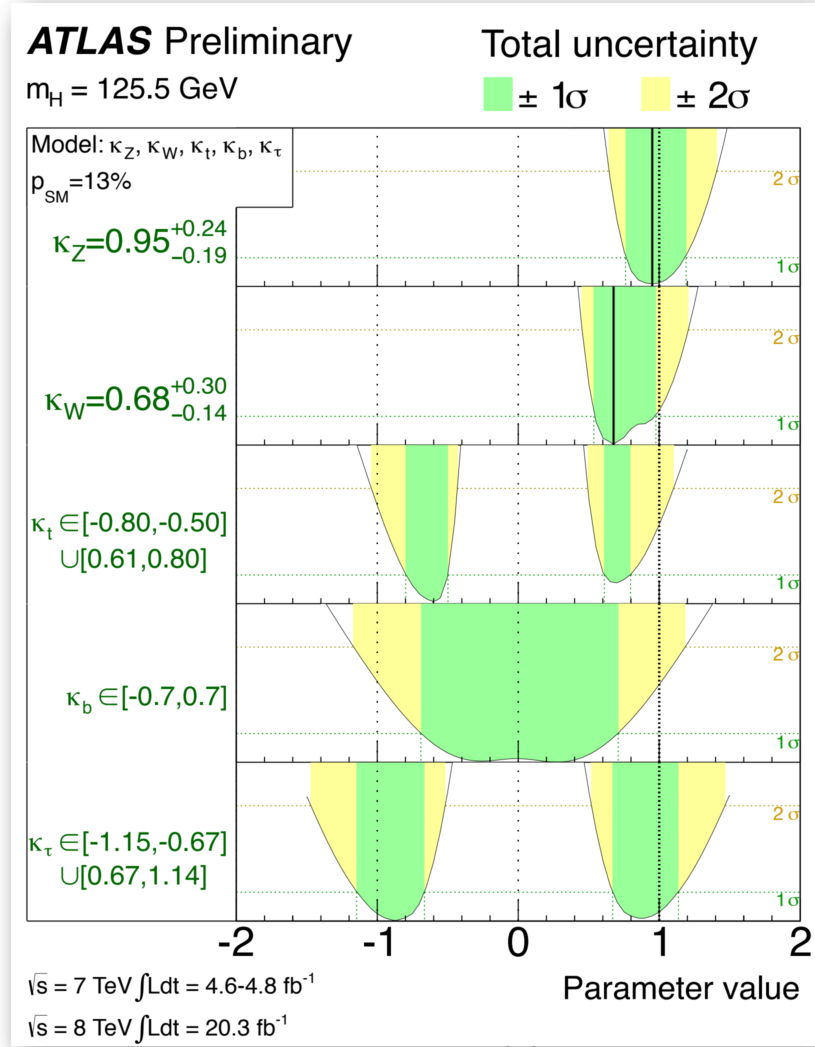
SM Higgs studies and couplings using 100 TeV collider
Ian Low (Northwestern Univ. and ANL)
Higgs related SUSY and BSM phenomena
Prof. Carlos Wagner (University of Chicago and ANL)
Di- and Triple-Higgs studies
Dr. Chien-Yi Chen (Brookhaven National Laboratory)
Higgs and SM Physics Highlights from the LHC
Jeffrey Berryhill (Fermilab)
Prospects of Higgs and SM measurements at HL-LHC
Hidetoshi Otono (Kyushu, Japan)

LHC (now): Higgs

CMS-PAS-HIG-14-009



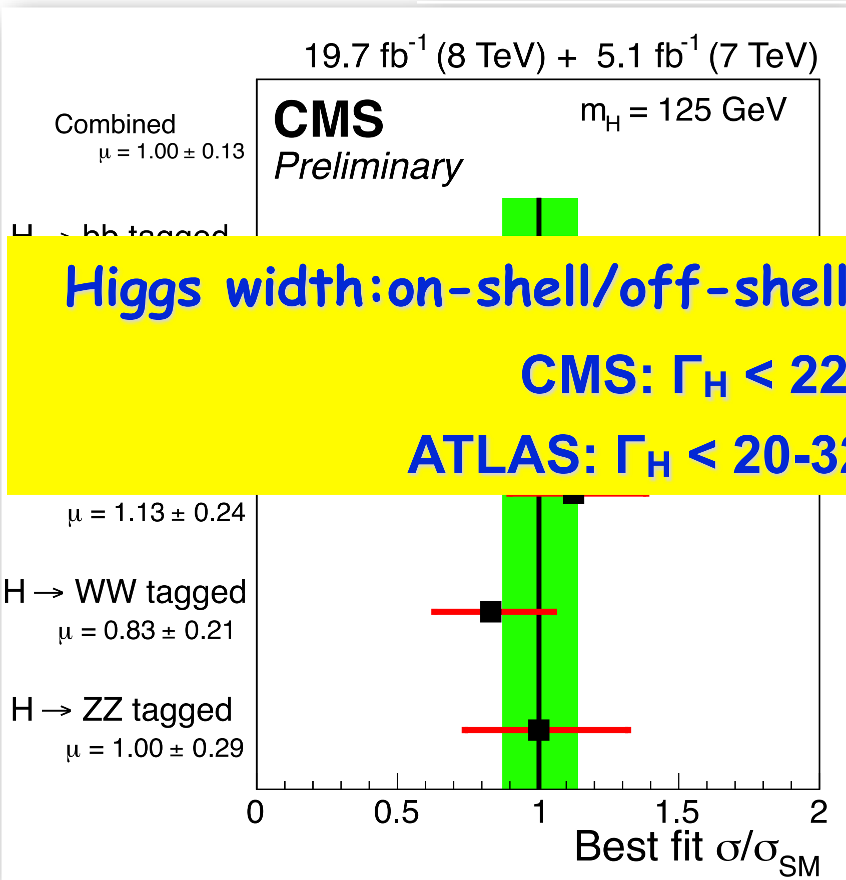
ATLAS-CONF-14-009

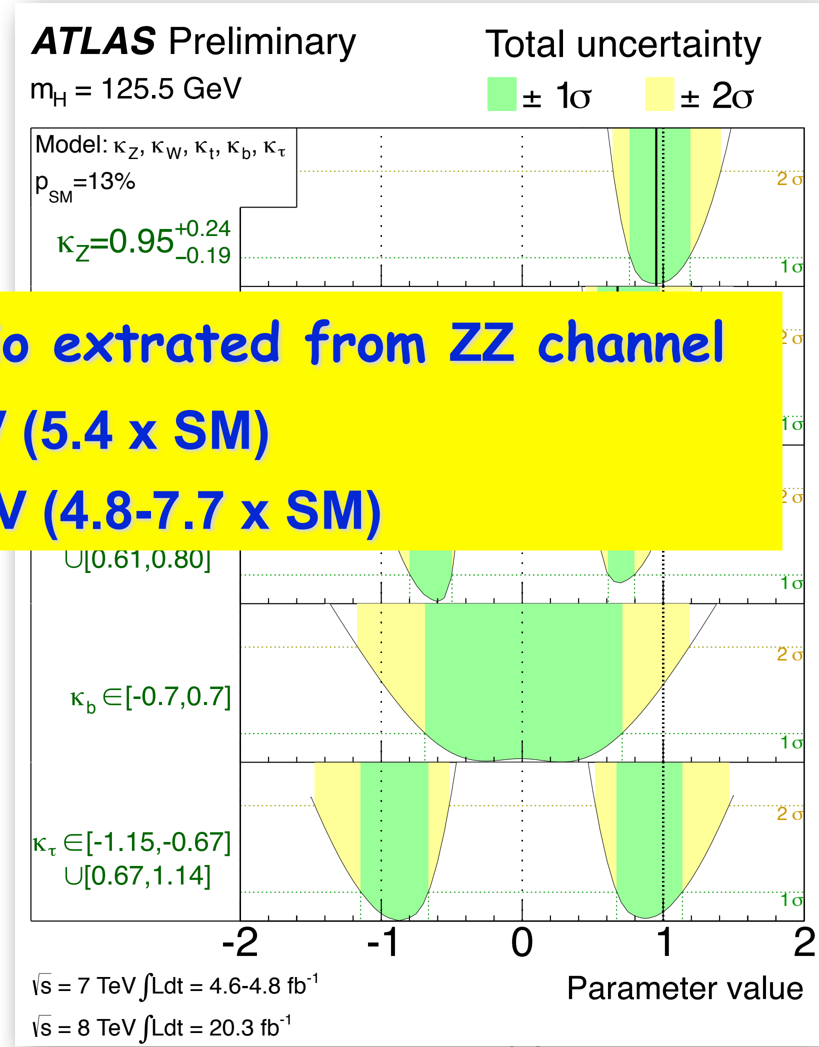


LHC (now): Higgs

ATLAS-CONF-14-009

CMS-PAS-HIG-14-009





Higgs width:on-shell/off-shell ratio extrated from ZZ channel

CMS: Γ_H < 22 MeV (5.4 x SM)

ATLAS: Γ_H < 20-32 MeV (4.8-7.7 x SM)

LHC, HL-LHC: Higgs

Prospects of Higgs and SM measurements at HL-LHC
Hidetoshi Otono (Kyushu, Japan)

Higgs factory

- 170 M Higgs produced in each experiment, ~ 2 M events after selection
- rare decays: μμ, Zγ, factor of 2 enhancement from 300 fb^{-1} to 3 ab^{-1}

Snowmass Higgs Working Group, 1310.8361

Luminosity	300 fb^{-1}	3000 fb^{-1}
Coupling parameter	7-parameter fit	
κ_γ	$5-7\%$	$2-5\%$
κ_g	$6-8\%$	$3-5\%$
κ_W	$4-6\%$	$2-5\%$
κ_Z	$4-6\%$	$2-4\%$
κ_u	$14-15\%$	$7-10\%$
κ_d	$10-13\%$	$4-7\%$
κ_ℓ	$6-8\%$	$2-5\%$
Γ_H	$12-15\%$	$5-8\%$

Factor of 1.5-2 better.

New physics contribution

$$\frac{\delta g_{\mathrm{HXX}}}{g^{\mathrm{SM}}_{\mathrm{HXX}}} \leq 5\% \times \left(\frac{1\mathrm{TeV}}{\Lambda}\right)^2$$

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim -.4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

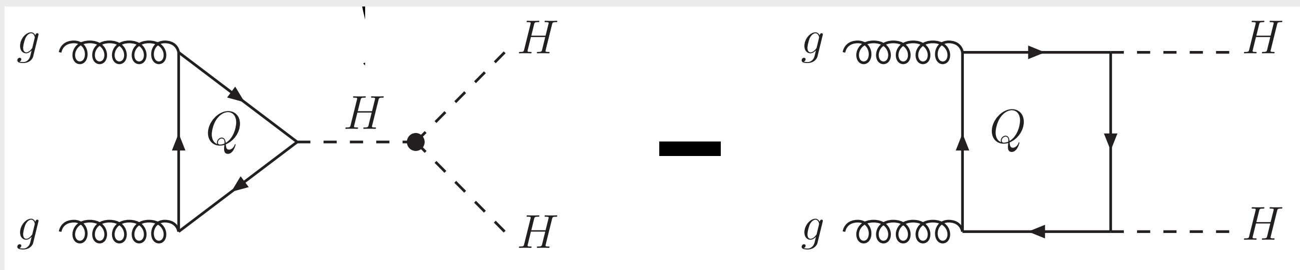
Might be good for some new physics with scale < 1 TeV

S. Su

SM Higgs studies and couplings using 100 TeV collider
Ian Low (Argonne National Laboratory)

HL-LHC: Higgs self-coupling

Negative interference reduces the sensitivity to g_{HHH}



With 3 ab^{-1}

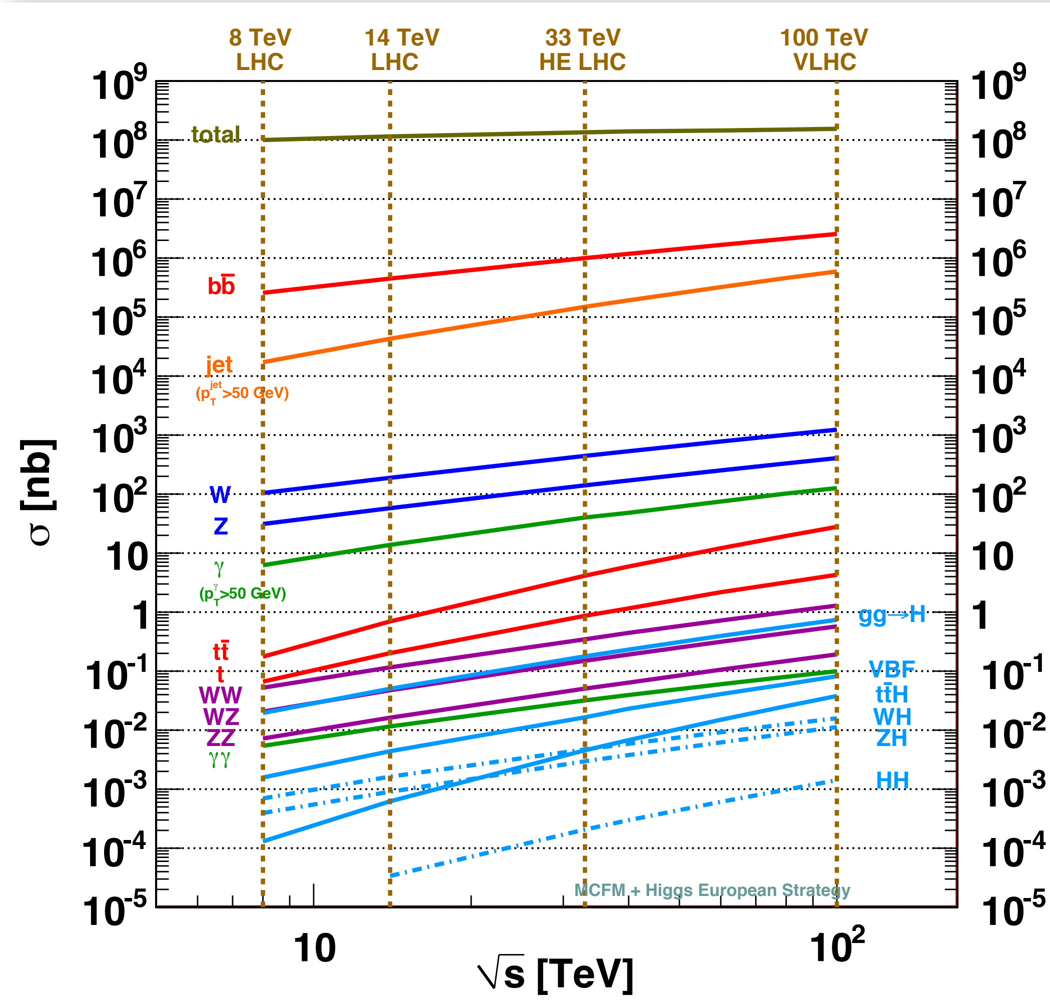
Expected events

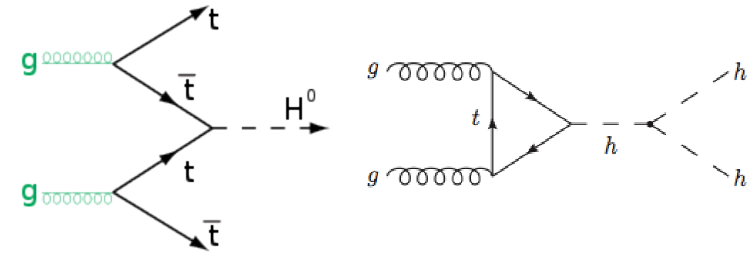
bbWW	30000
bbττ	9000
WWWW	6000
γγbb	320
γγγγ	1

- A sensitivity of 30-50% might be achieved for bbγγ
- New physics deviation typically less than 20%

Di- and Triple-Higgs studies
Dr. Chien-Yi Chen (Brookhaven National Laboratory)

100 TeV pp: Higgs



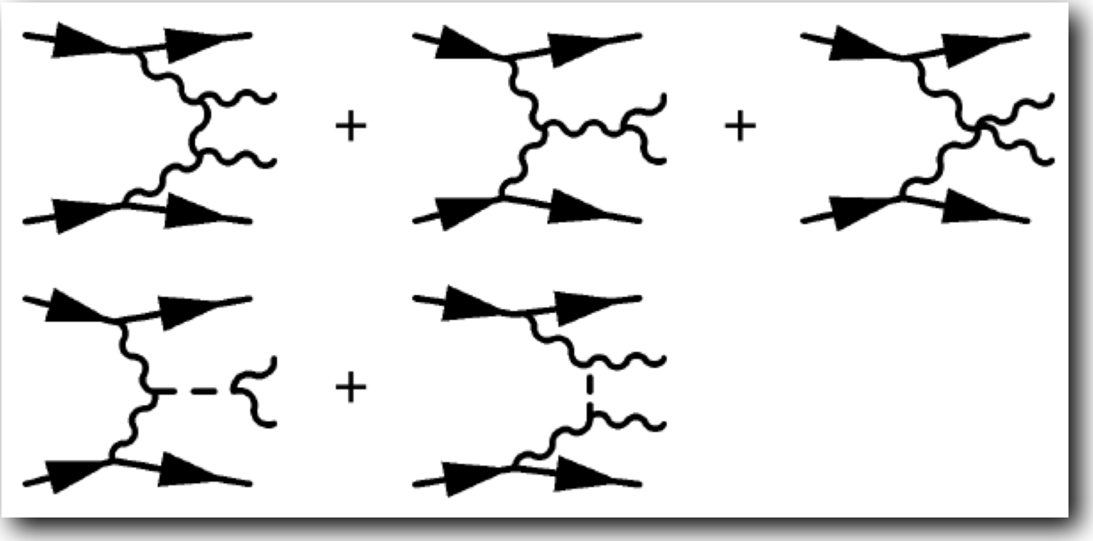


Process	σ (100 TeV)/σ (14 TeV)
Total pp	1.25
W	~7
Z	~7
WW	~10
ZZ	~10
tt	~30
H	~15 (ttH ~60)
HH	~40
stop (m=1 TeV)	$\sim 10^3$

λ_t : 1%

λ : 8%

WW scattering?



W_L W_L scattering and VBF Physics at 100 TeV Collider
Prof. Ashutosh Kotwal (Duke University)
Higgs and SM Physics Highlights from the LHC
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Prospects of New Physics searches using HL-LHC
Altan Cakir (DESY)

BSM Higgs Sectors

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- Implication of SM-like Higgs on BSM models
- Direct search for BSM Higgses

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Extended Higgs sector (other Higgs)
Dr. John Stupak (Purdue University Calumet)
Higgs related SUSY and BSM phenomena
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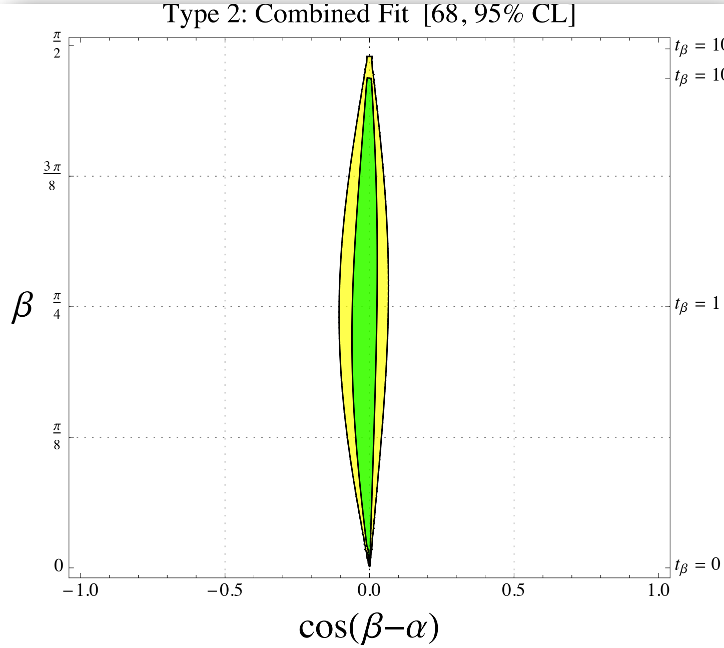
LHC: H_{SM} implication on 2HDM

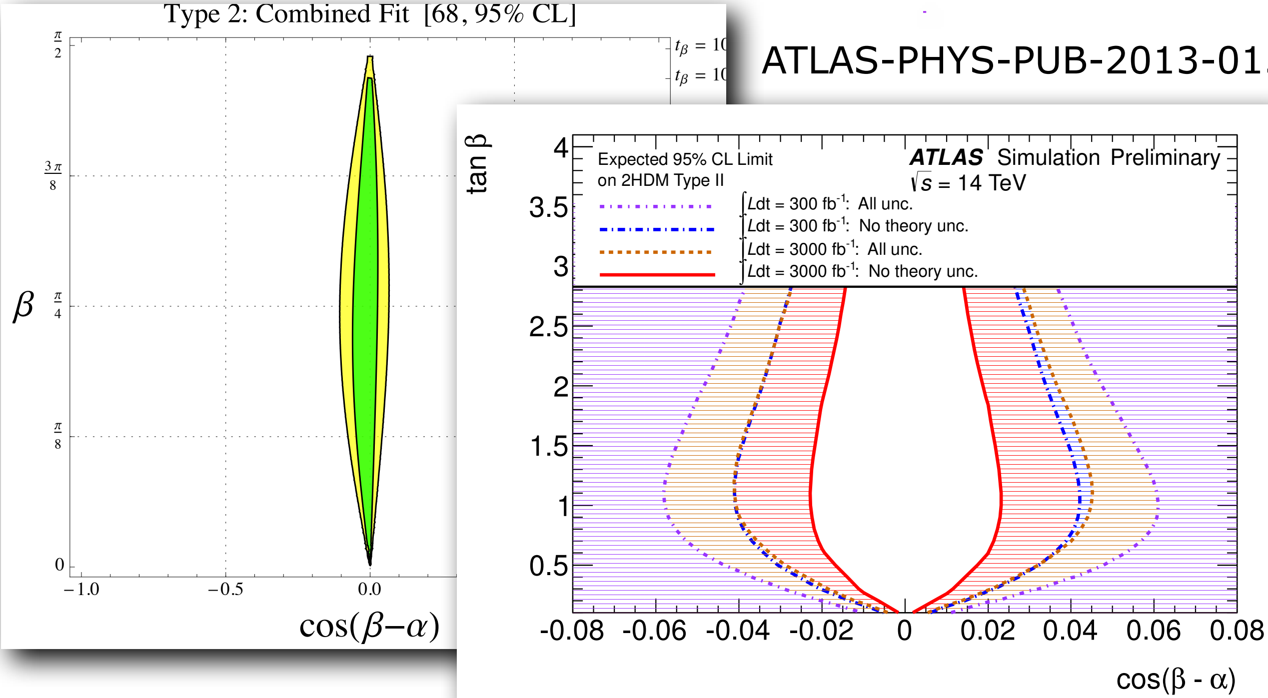


Craig, Galloway, Thomas, 1305.2424

Extended Higgs sector (other Higgs)
Dr. John Stupak (Purdue University Calumet)

LHC: H_{SM} implication on 2HDM

ATLAS-PHYS-PUB-2013-015



Craig, Galloway, Thomas, 1305.2424

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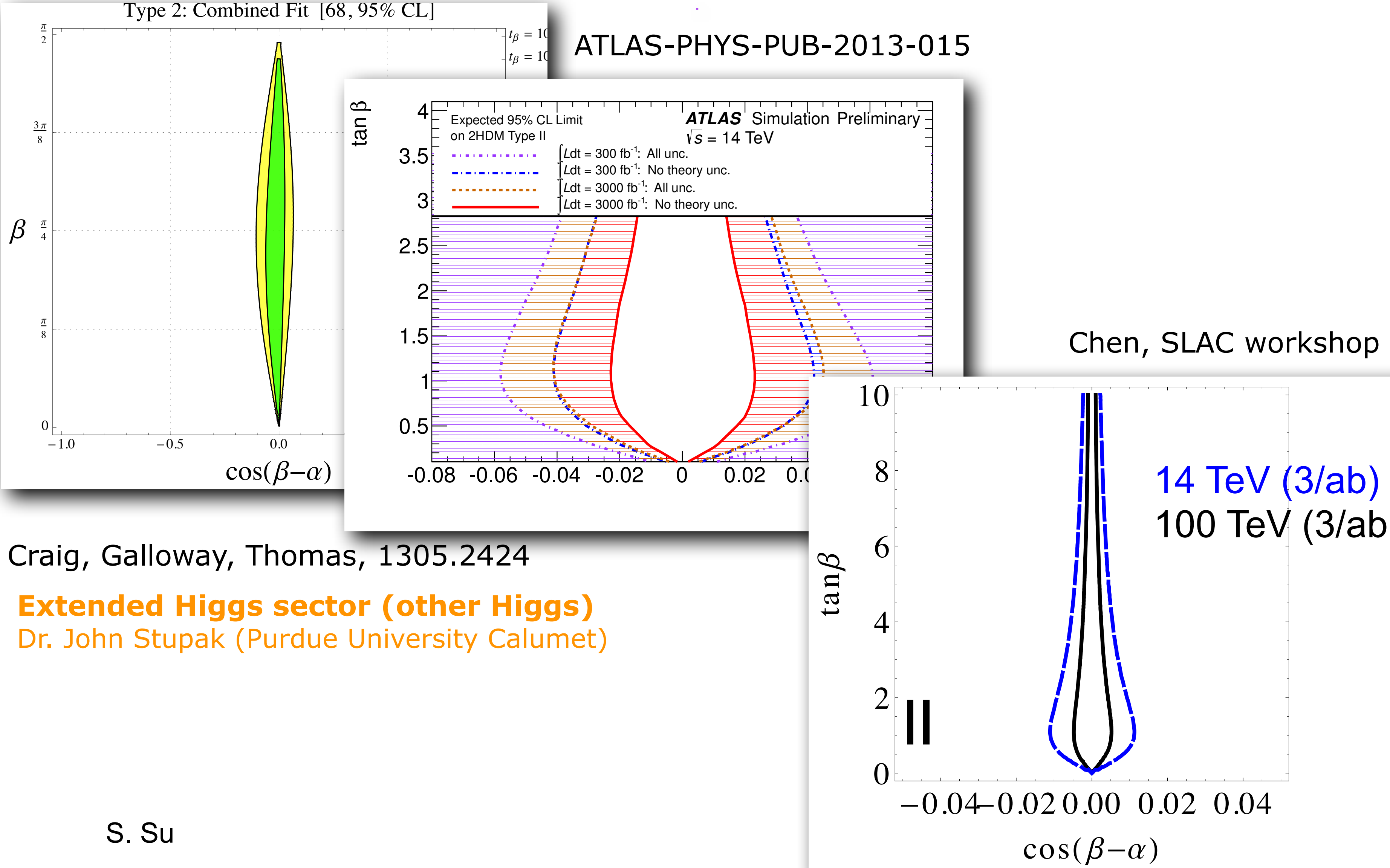
LHC: H_{SM} implication on 2HDM

ATLAS-PHYS-PUB-2013-015

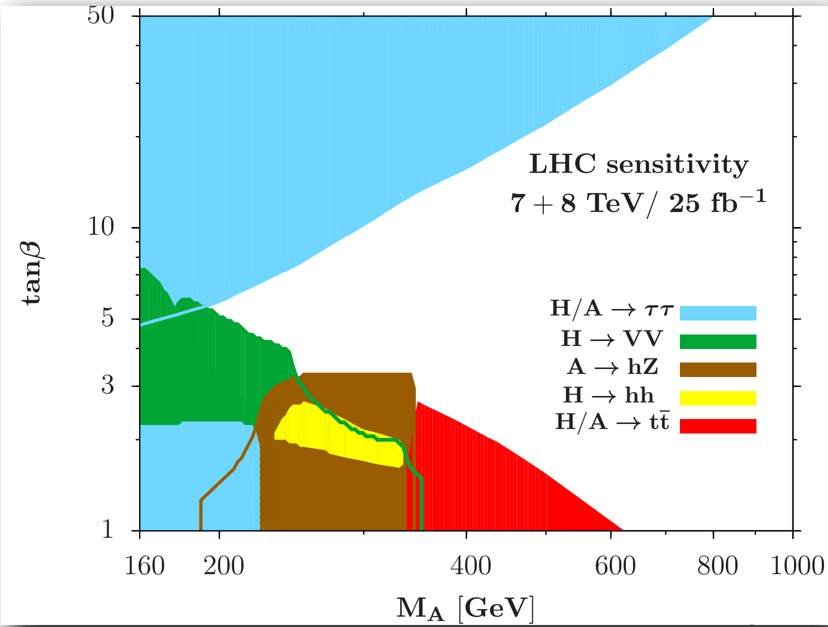
Chen, SLAC workshop



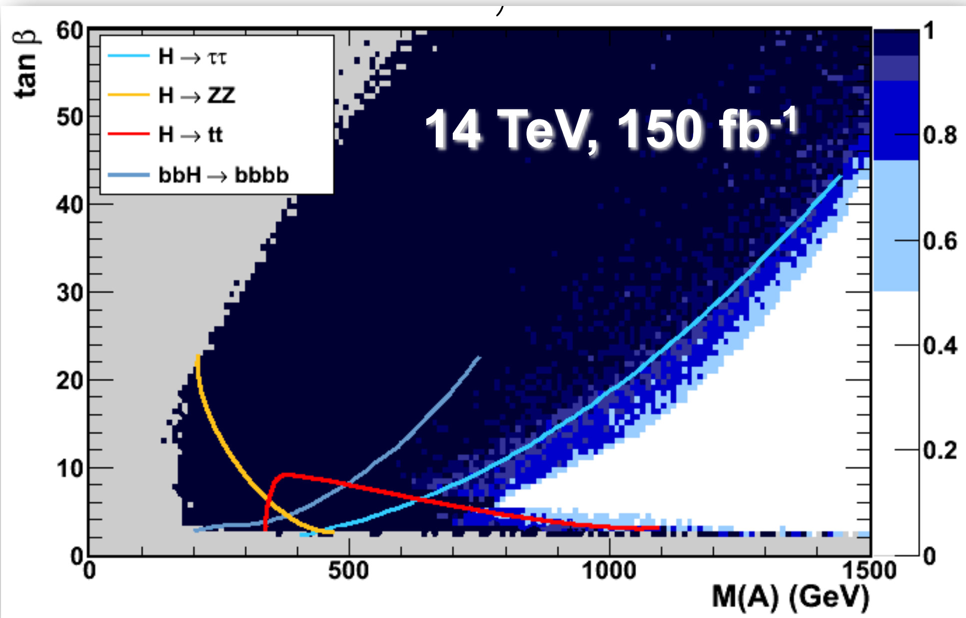
Craig, Galloway, Thomas, 1305.2424

S. Su

LHC: MSSM

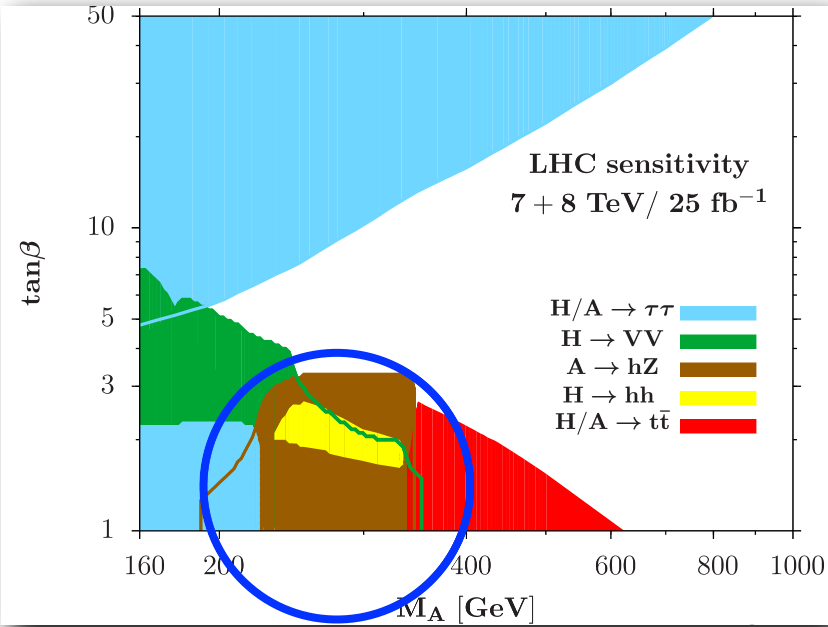


Snowmass 2013, Higgs working group



Arbey, Battaglia, Mahmoudi (2013)

LHC: MSSM



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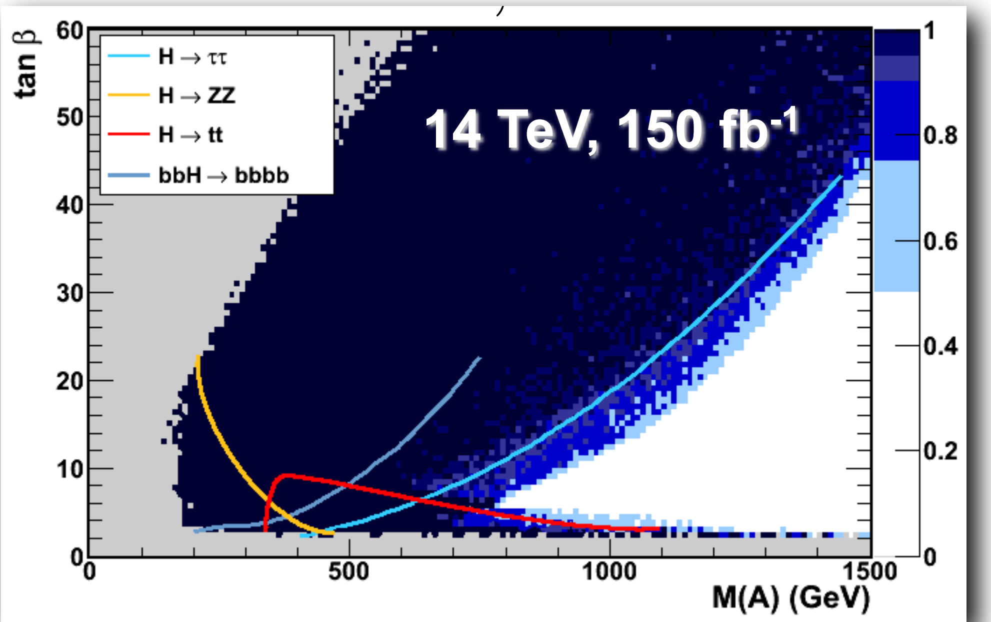
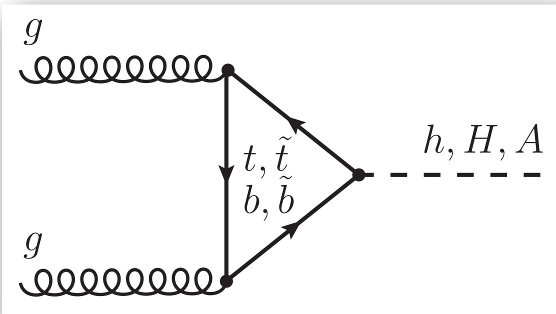
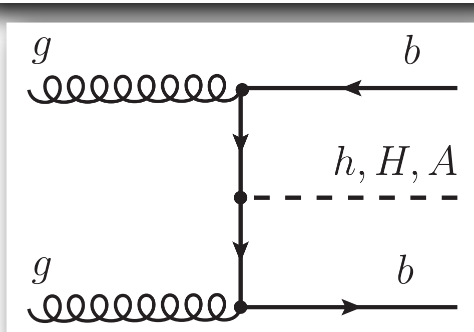


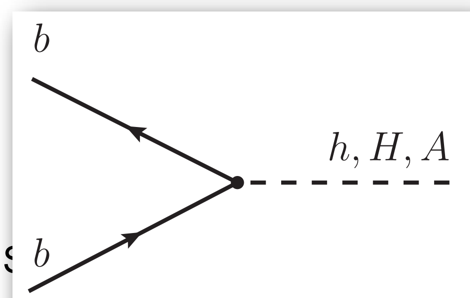
Arbey, Battaglia, Mahmoudi (2013)

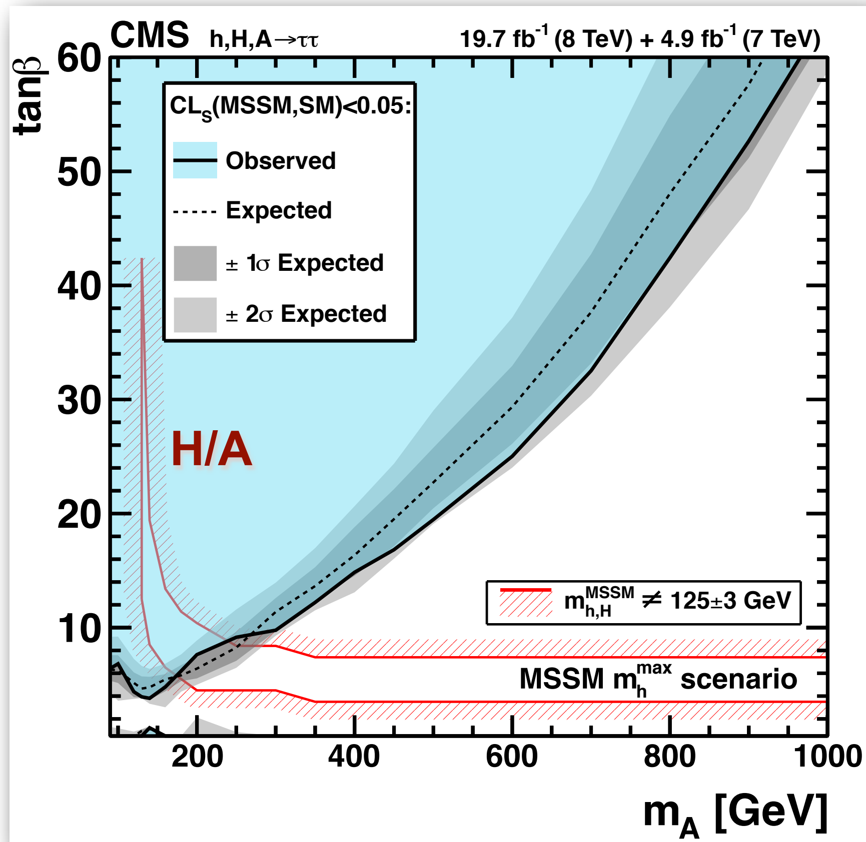
LHC(now): BSM Higgses

Conventional search channel: H/A → γγ, ZZ, WW, ττ, bb
(even for non-SM Higgs)









CMS: 1408.3316

Exotic Decay for Other Higgses

HH type	$(bb/\tau\tau/WW/ZZ)(bb/\tau\tau/WW/ZZ)$	$h_{SM} \to AA$, $H \to h_{SM}\, h_{SM}$, $H \to AA$, $A_i \to H_j A_k$,...
H^+H^- type	$(\tau\nu/tb)(\tau\nu/tb)$	$H/A \to H^+H^-$
ZH type	$(ll/qq/\nu\nu)(bb/\tau\tau/WW/ZZ)$	$h_{SM} \to ZA$, $A \to Zh_{SM}$, ...
$WH^\pm$ type	$(l\nu/qq')\ (\tau\nu/tb)$	$H/A \to WH^\pm$
WH type	$(l\nu/qq')(bb/\tau\tau/WW/ZZ)$	$tH^\pm$ production, $H^\pm \to WH$ $H^\pm \to WA$

Relax current limits

New channels open up for non-SM Higgs decay

S. Su

Exotic Decay for Other Higgses

HH type	(bb/ττ/WW/ZZ)(bb/ττ/WW/ZZ)	$h_{SM} \to AA$, $H \to h_{SM}\, h_{SM}$, $H \to AA$, $A_i \to H_j A_k$,...
H^+H^- type	(τν/tb)(τν/tb)	$H/A \to H^+H^-$
ZH type	(ll/qq/νν)(bb/ττ/WW/ZZ)	$h_{SM} \to ZA$, $A \to Z h_{SM}$, ...
$WH^\pm$ type	(lν/qq') (τν/tb)	$H/A \to WH^\pm$
WH type	(lν/qq')(bb/ττ/WW/ZZ)	$tH^\pm$ production, $H^\pm \to WH$ $H^\pm \to WA$

Relax current limits

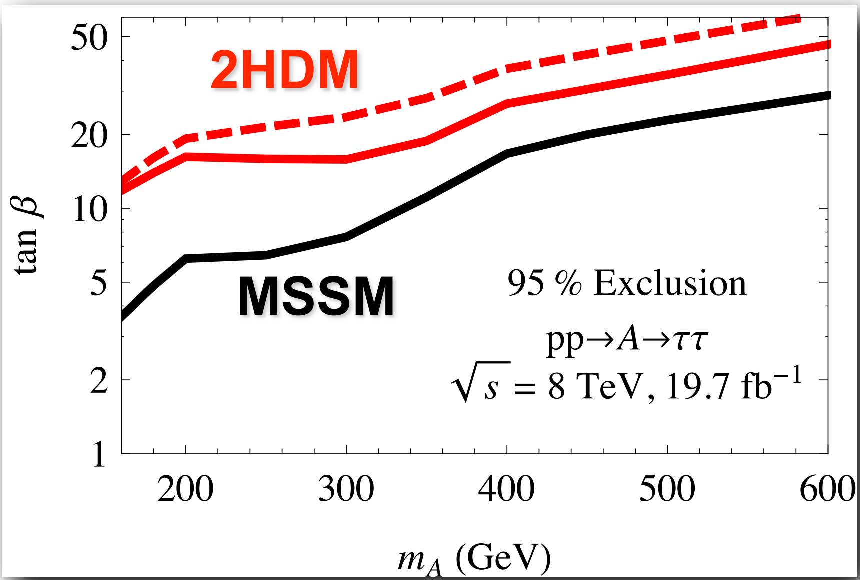
New channels open up for non-SM Higgs decay

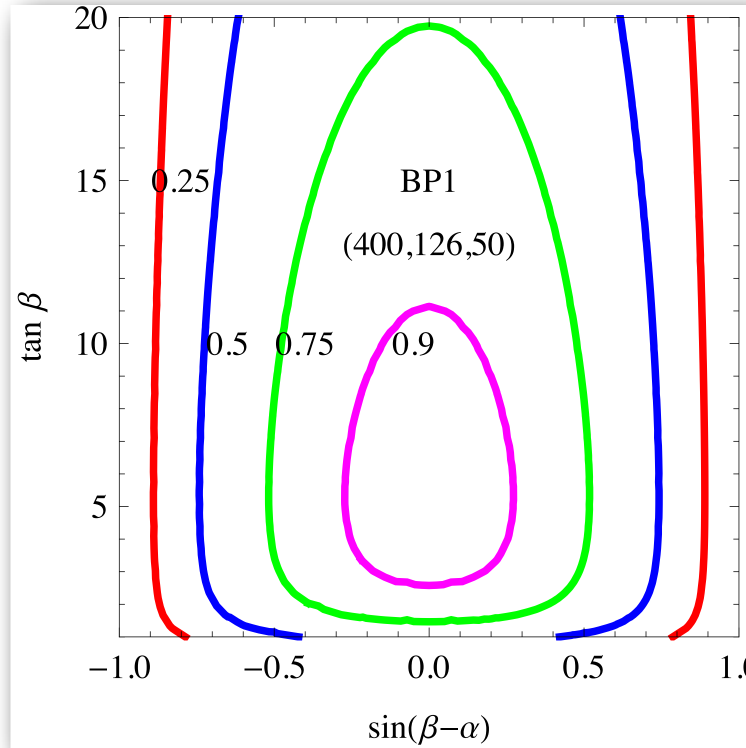
S. Su

LHC: H/A ➔ AZ/HZ

pp→H/A → ττ

pp→H/A→AZ/HZ→ ττ ll, bbll



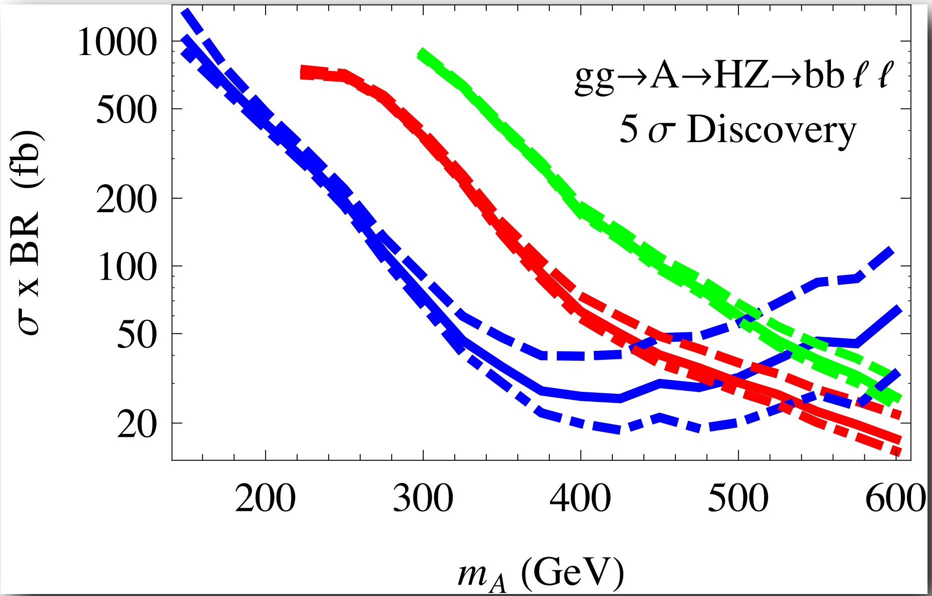


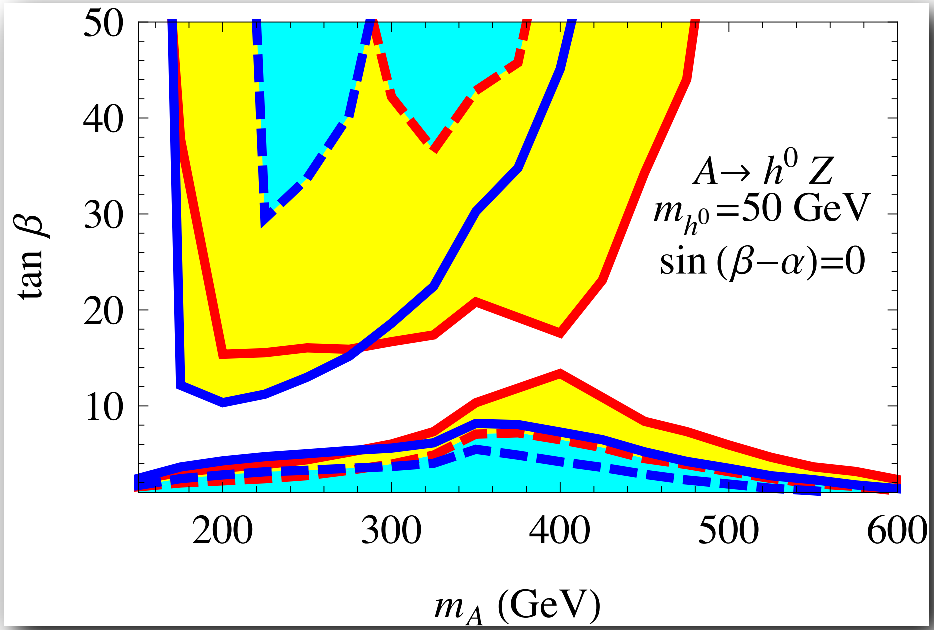
B. Coleppa, F. Kling, SS (2014)

LHC: H/A ➔ AZ/HZ

pp→H/A→AZ/HZ→ ττ ll, bbll

LHC 14, 100 fb^{-1}





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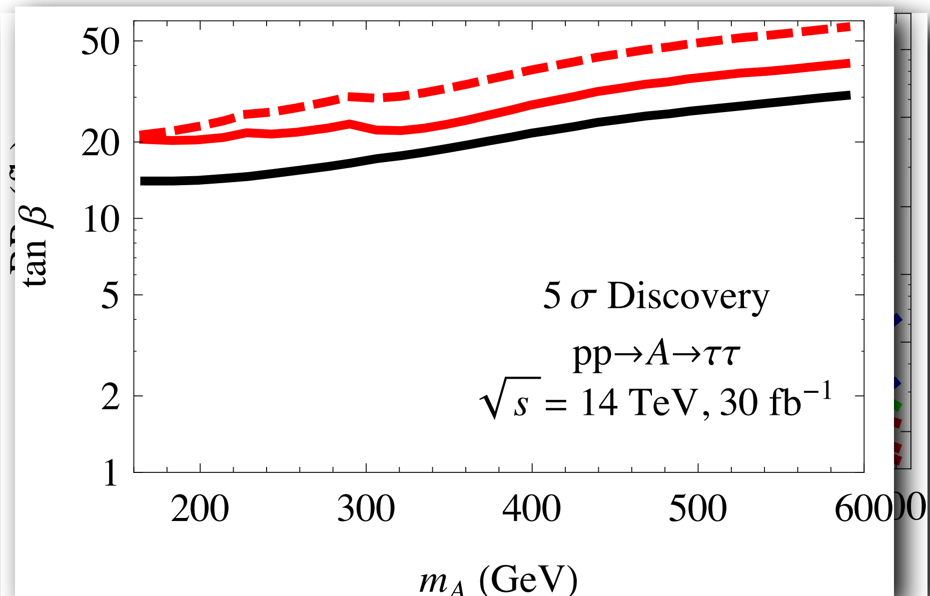
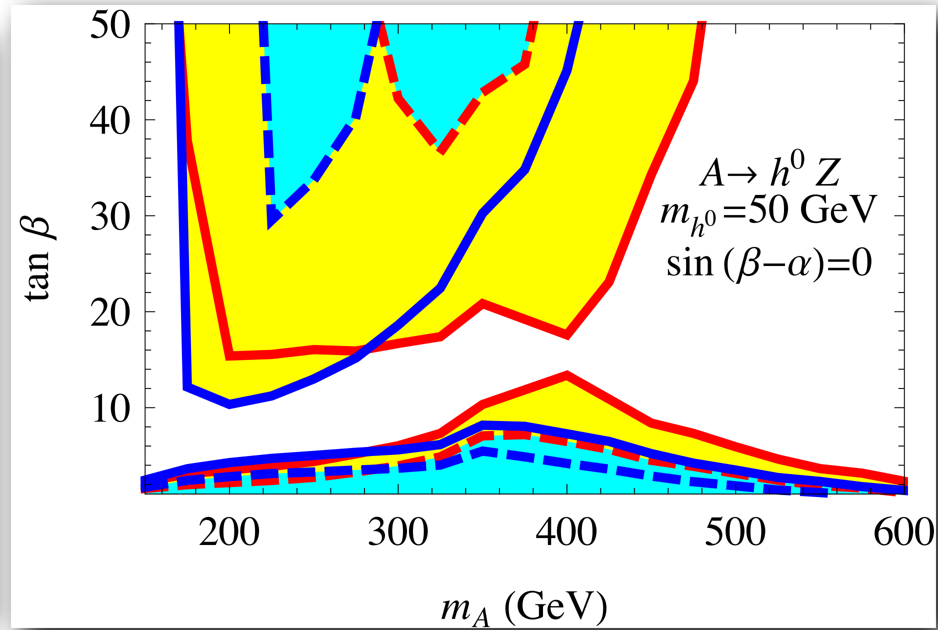
LHC 14, 100 fb^{-1}



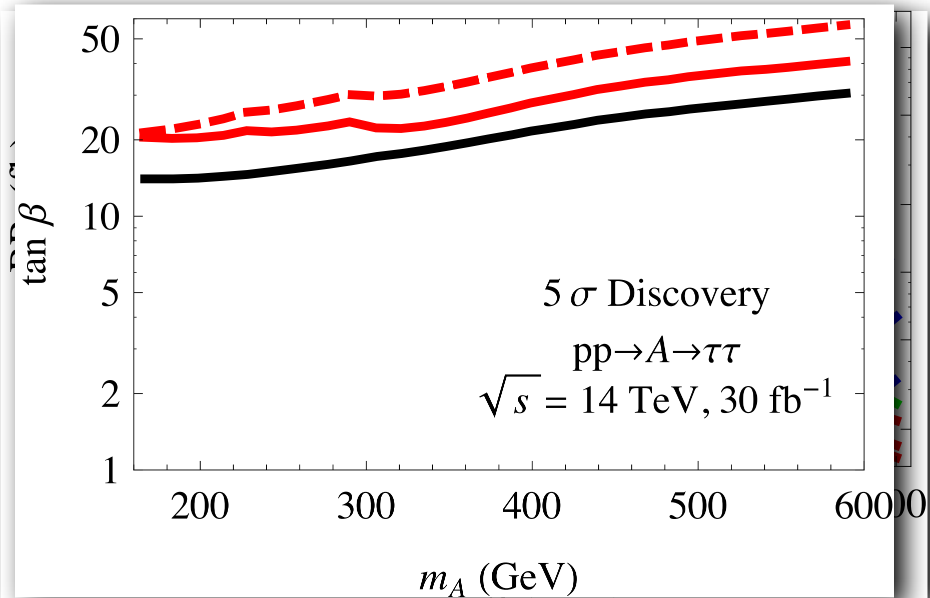


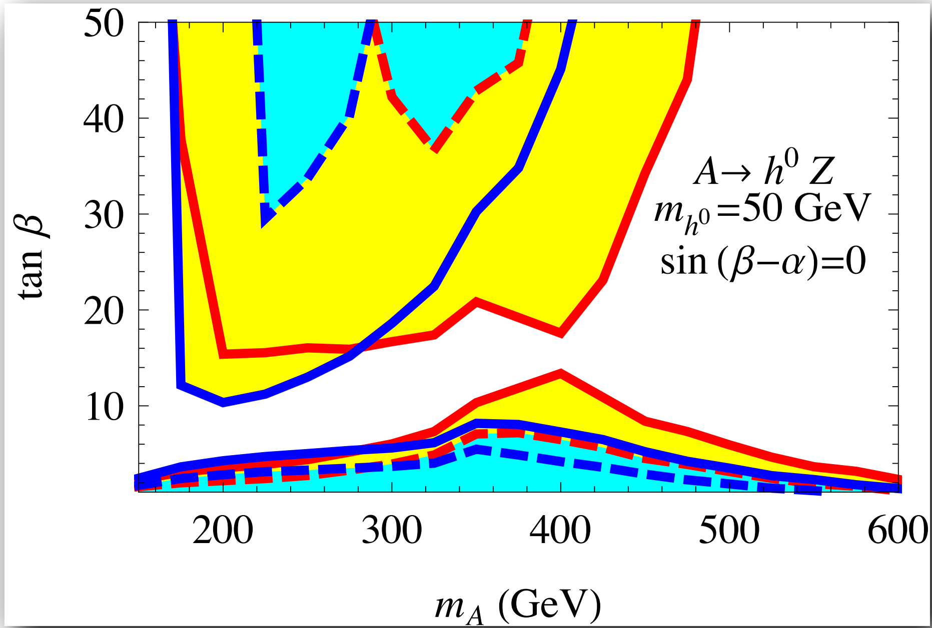
B. Coleppa, F. Kling, SS (2014)

LHC: H/A ➔ AZ/HZ

pp→H/A→AZ/HZ→ ττ ll, bbll

LHC 14, 100 fb⁻¹





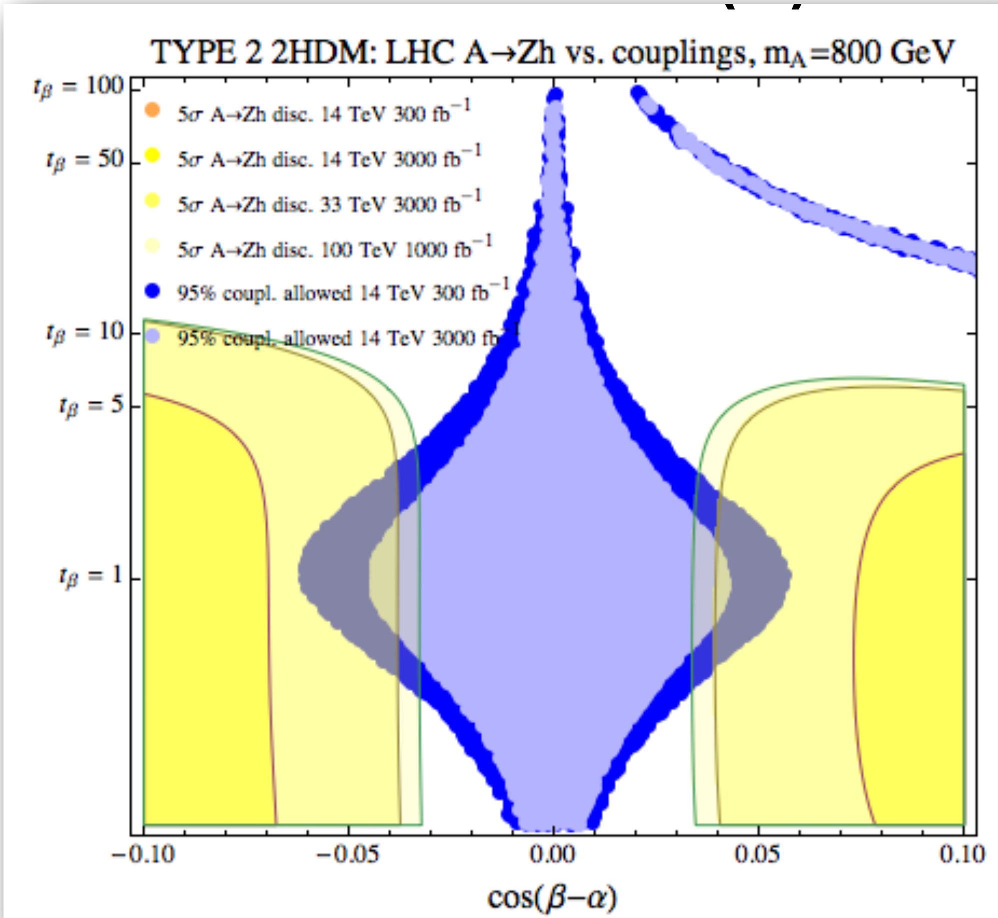
B. Coleppa, F. Kling, SS (2014)

complementary to the conventional ττ mode

LHC: H/A ➔ AZ/HZ

pp→H/A→AZ/HZ→ ττ ll, bbll

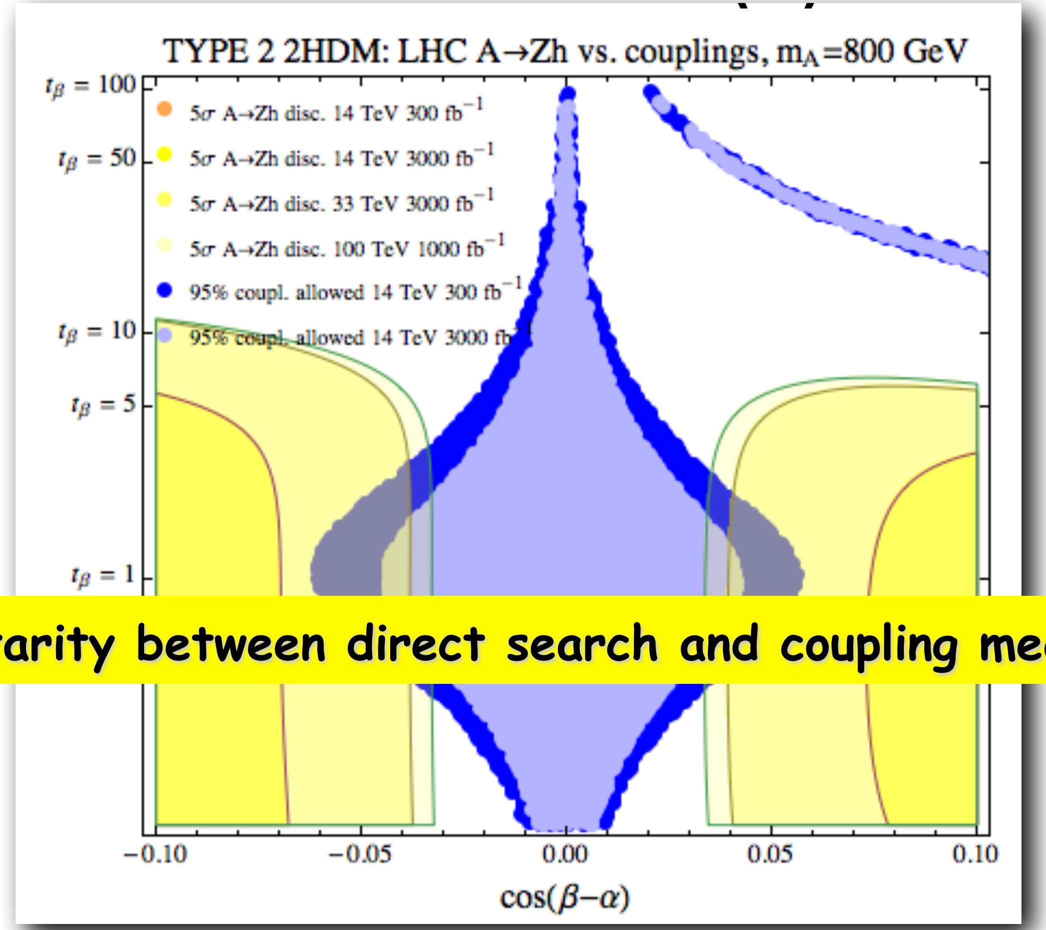
Brownson et. al., 1308.6334



LHC: H/A ➔ AZ/HZ

pp→H/A→AZ/HZ→ ττ ll, bbll

Brownson et. al., 1308.6334

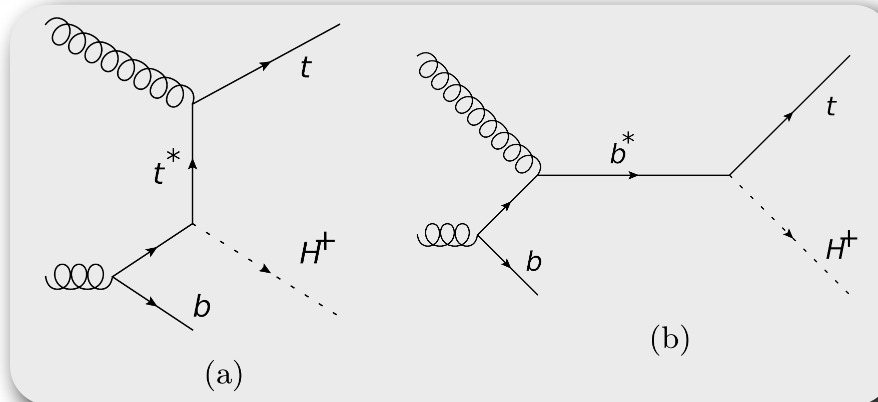


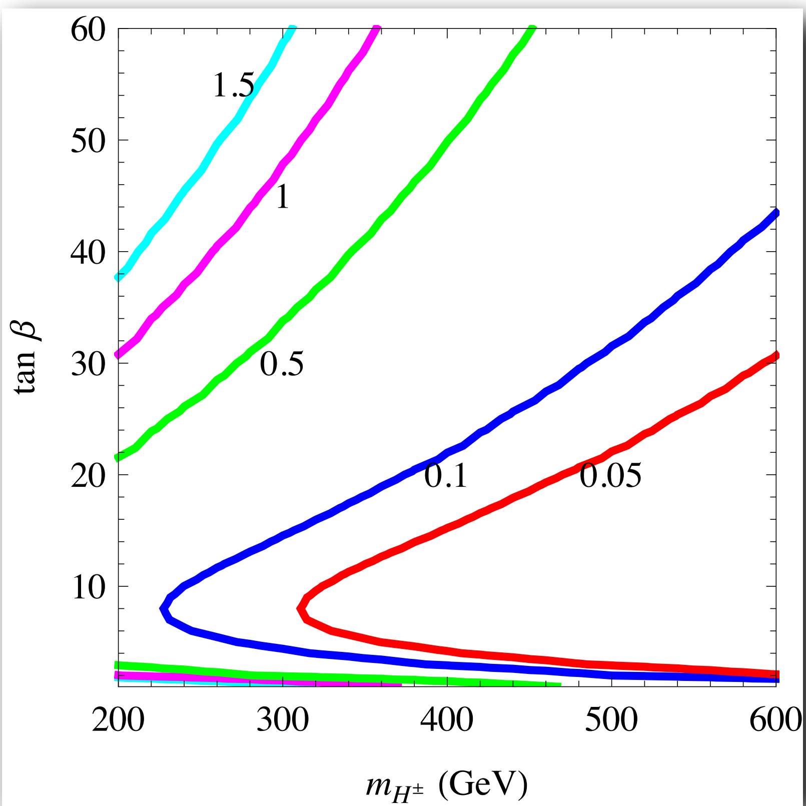
complementarity between direct search and coupling measurements.

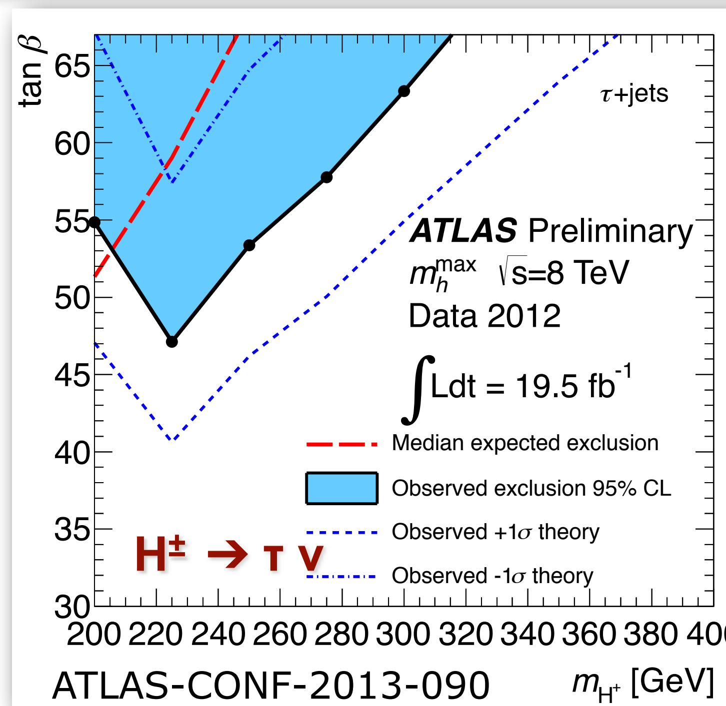
LHC: H$^\pm$ → AW/HW

Charged Higgs search is difficult!

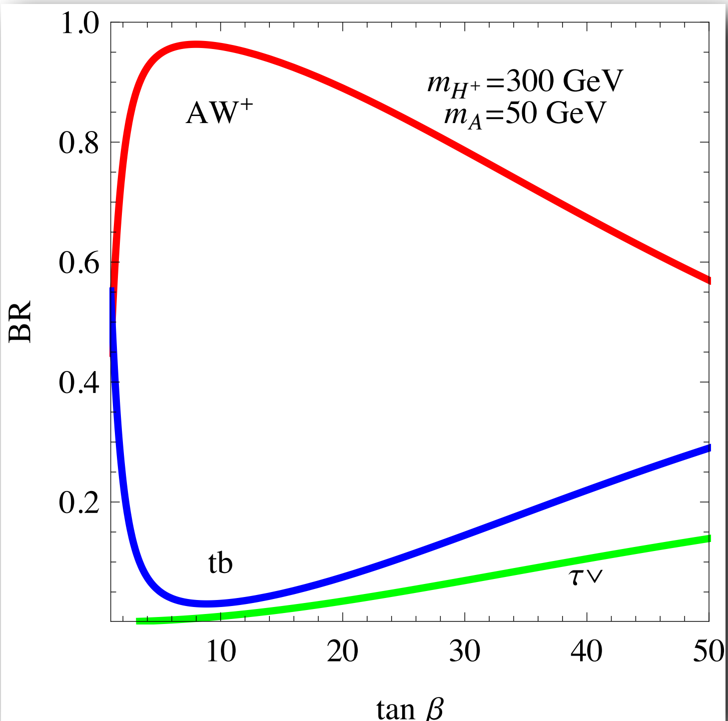
- small production cross section
- H$^\pm$ → tb, large backgrounds
- H$^\pm$ → τν, cs, suppressed signal



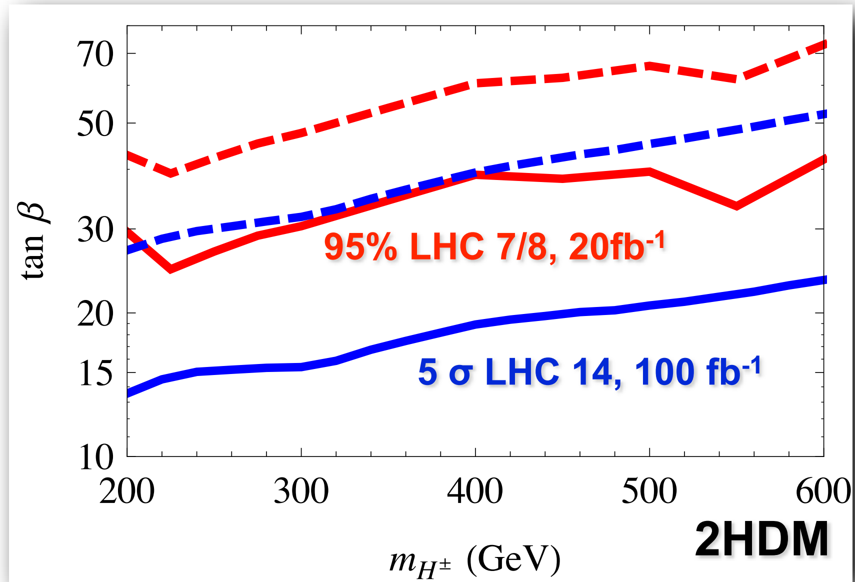




LHC: H$^\pm$



pp → H$^\pm$ tb → τν bbjj

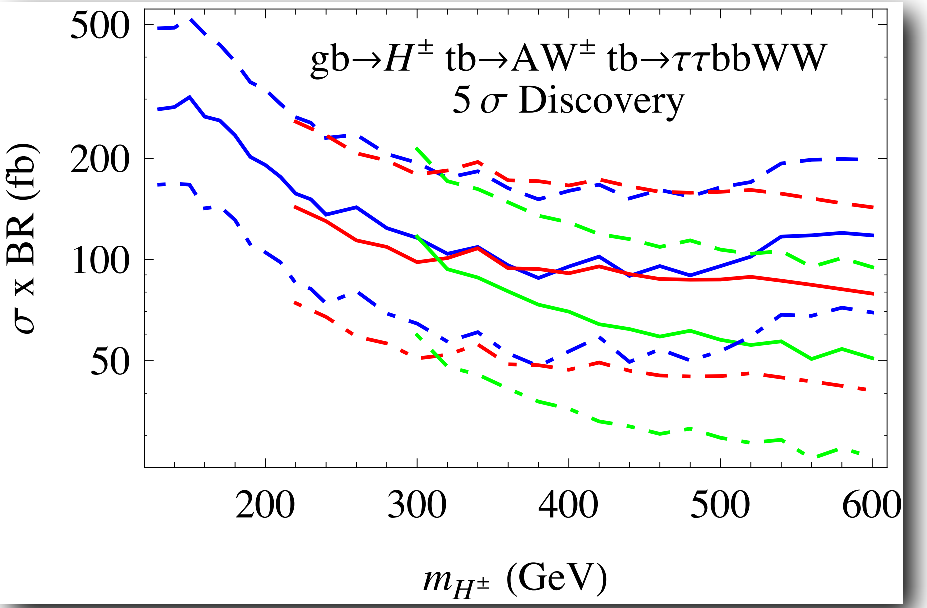


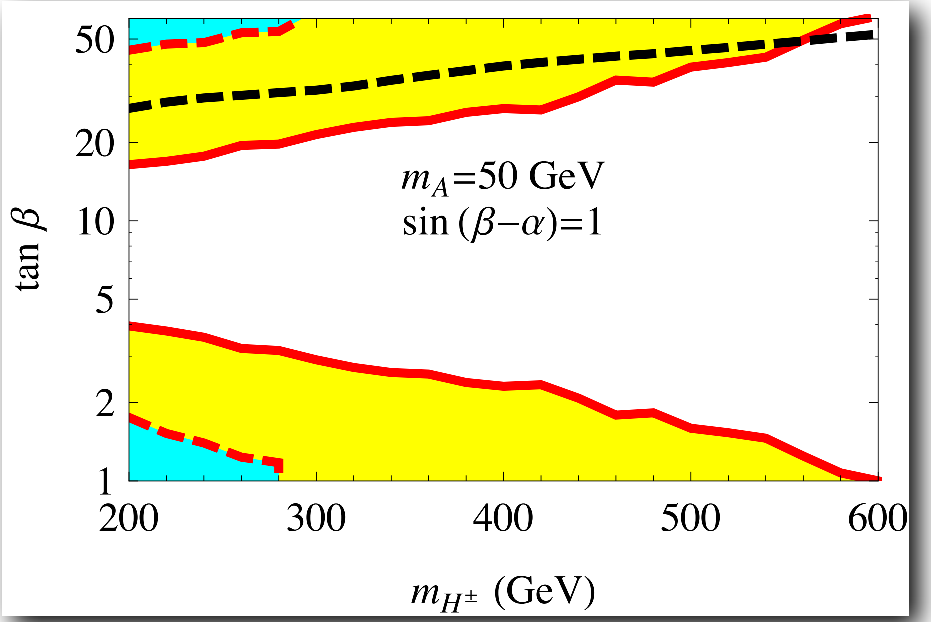
B. Coleppa, F. Kling, SS (2014)

LHC: $H^{\pm}$

$pp \to H^{\pm}\, tb \to AW/HW\, tb \to \tau\tau\, bb\, l\nu\, qq$

LHC 14, 300 fb^{-1}





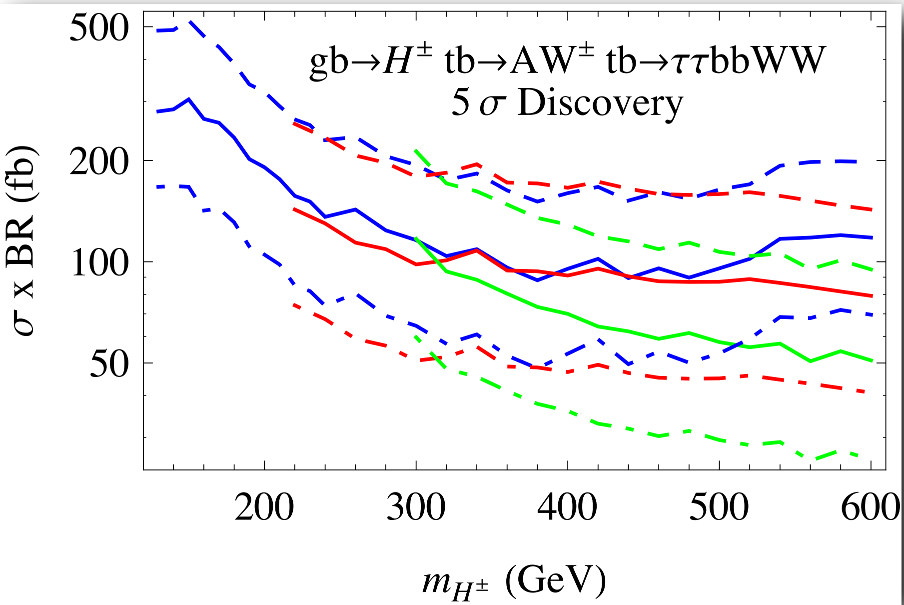
B. Coleppa, F. Kling, SS (2014)

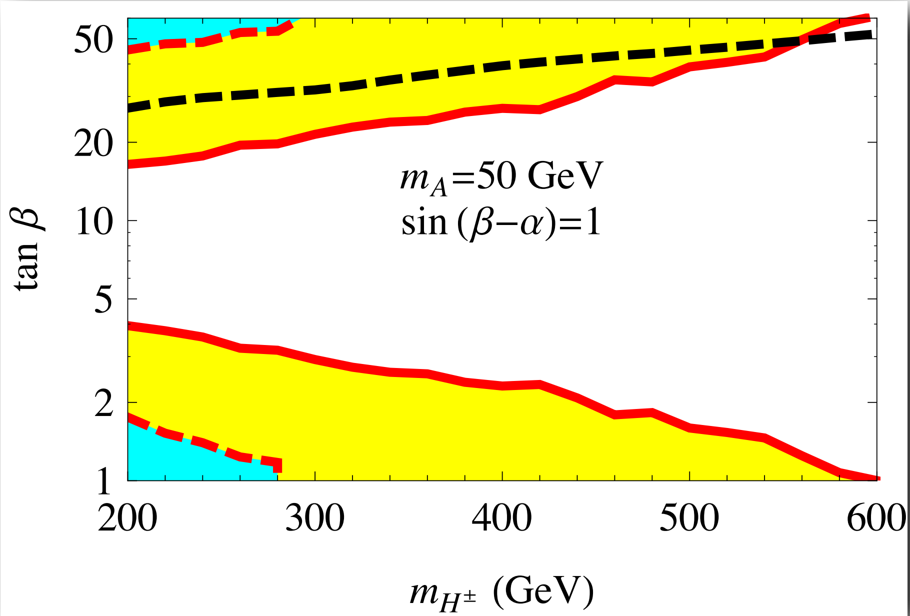
Type II 2HDM

LHC: H±

pp→H± tb→AW/HW tb→ ττ bb lν qq

LHC 14, 300 fb^{-1}





B. Coleppa, F. Kling, SS (2014)

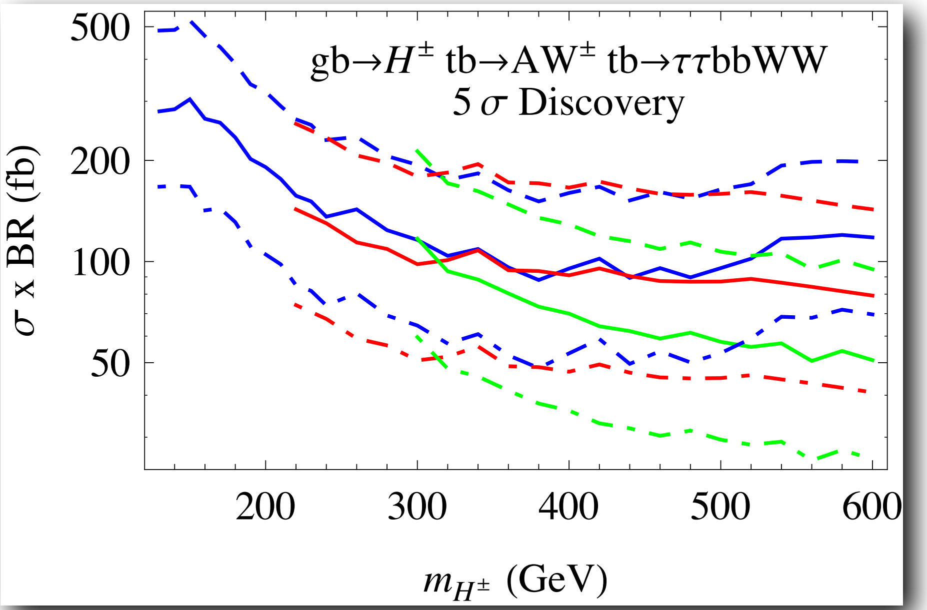
Type II 2HDM

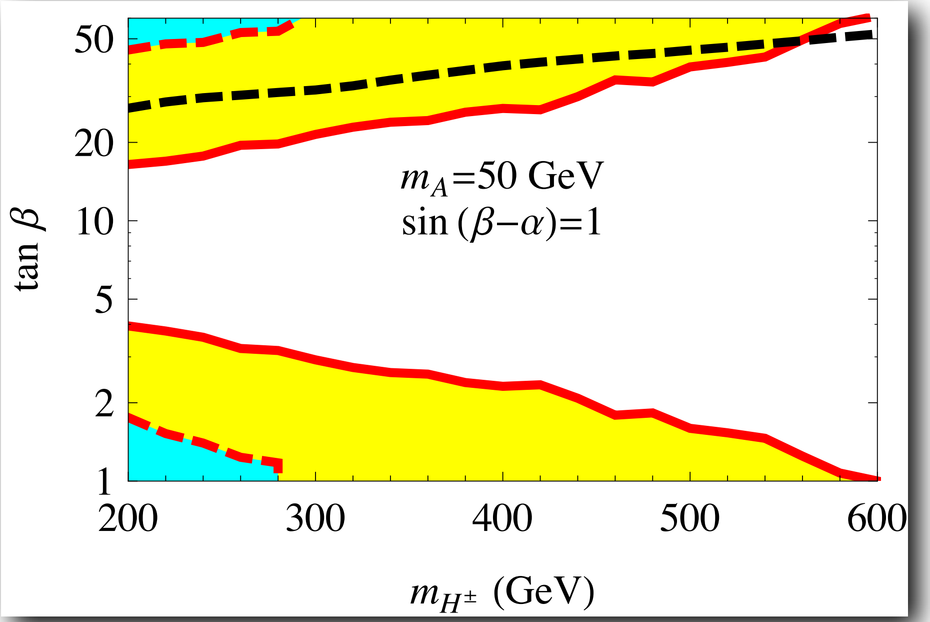
Reach at small tan β: complementary to the H± → τν channel

LHC: $H^{\pm}$

$pp \to H^{\pm}\, tb \to AW/HW\, tb \to \tau\tau\, bb\, l\nu\, qq$

LHC 14, 300 fb^{-1}





B. Coleppa, F. Kling, SS (2014)

Type II 2HDM

Reach at small tan β: complementary to the $H^{\pm} \to \tau\nu$ channel

100 TeV reach for BSM Higgses needed,

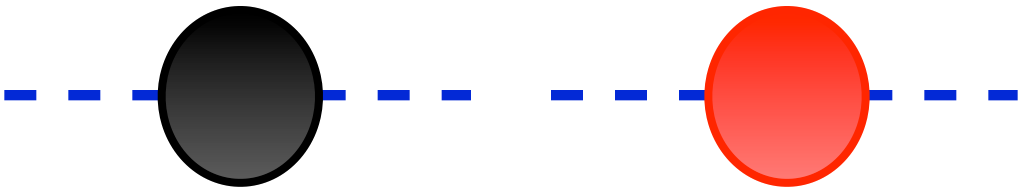
both for conventional channels and exotic channels.

S. Su

Naturalness and Top Partners

$$\epsilon \sim (125\ \mathrm{GeV}/M_{\mathrm{NP}})^2$$

Naturalness: Top Partner



$(m_H^2)_{physical} \sim (m_H^2)_{bare} \quad + \quad \Lambda_{cutoff}^2 \qquad - \quad \Lambda_{cutoff}^2$

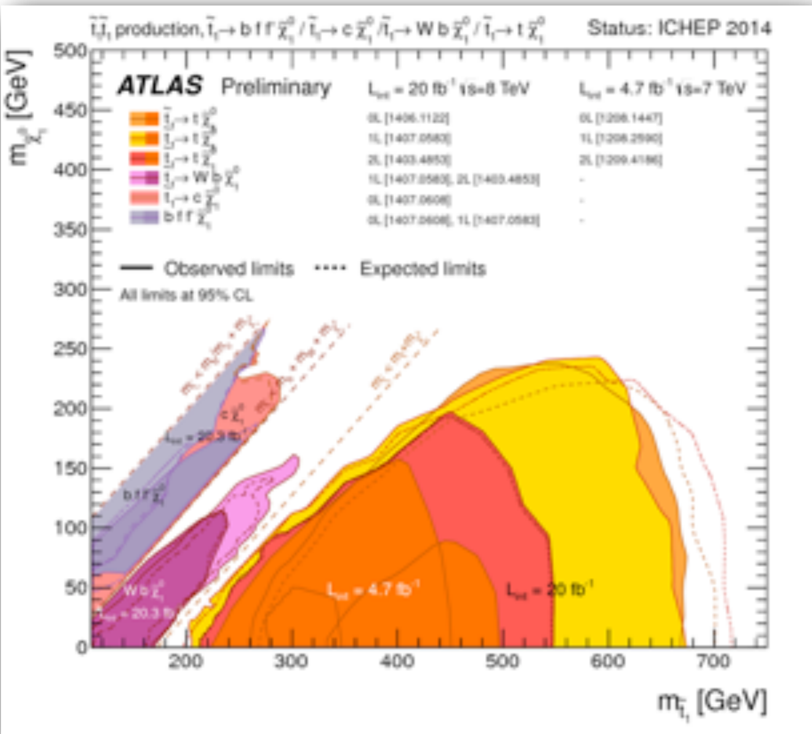
- A light Higgs mass and top contribution ⇒ top parter @ TeV scale
- top partner → top (or bW) + X

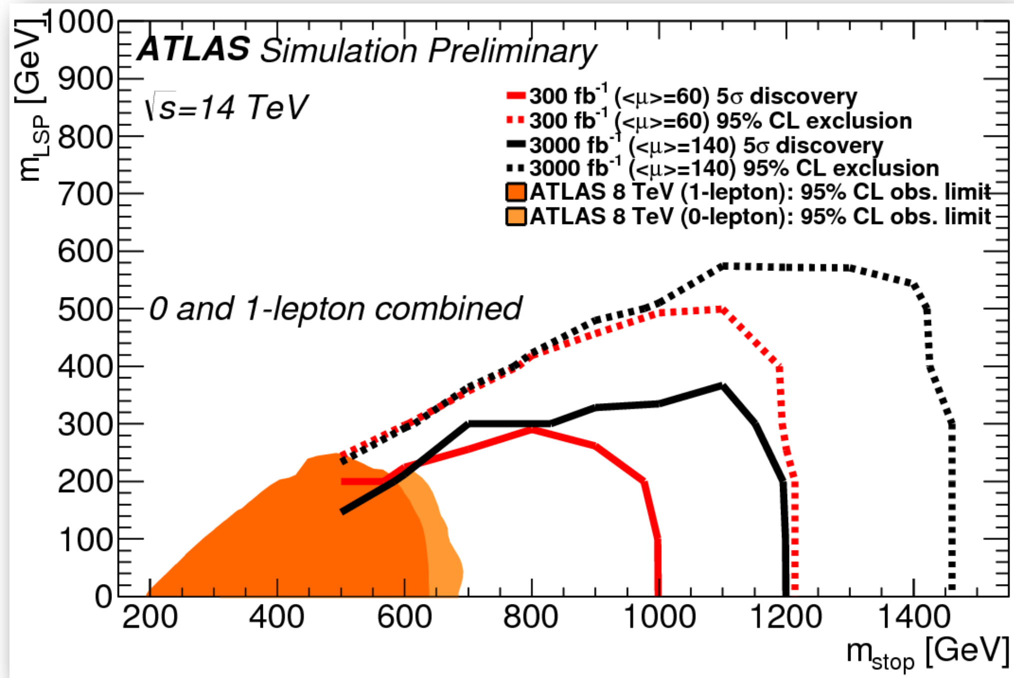
  Top partners including SUSY stop productions, Aram Avetisyan (Boston University)
  Composite Higgs, Giuliano Panico (CERN & ETH Zurich)

  decay might be highly suppressed.
- top partner not necessary charged under $SU(3)_C$

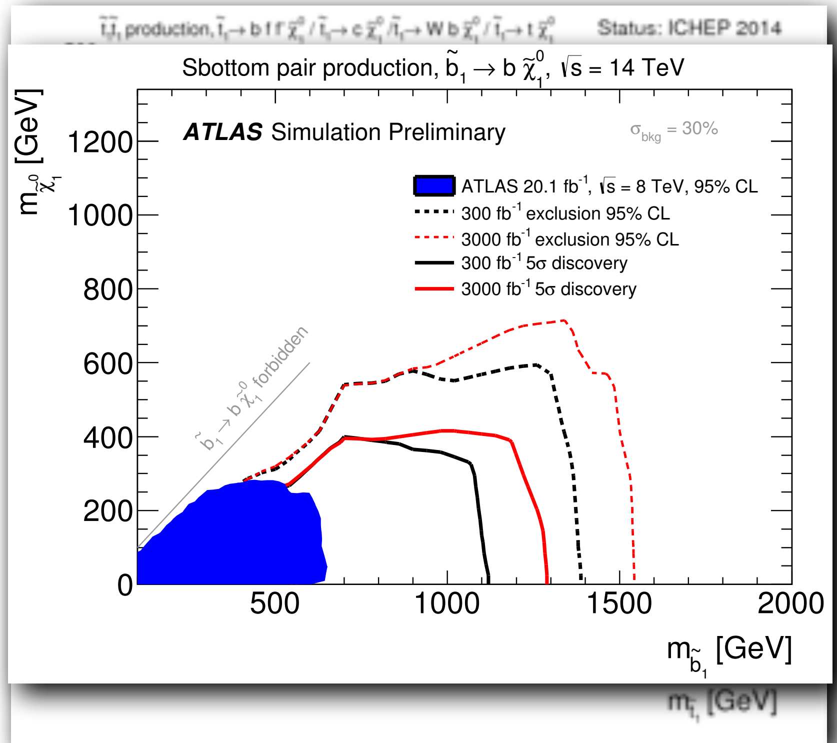
  could hide at the LHC or pp machine (strong production)

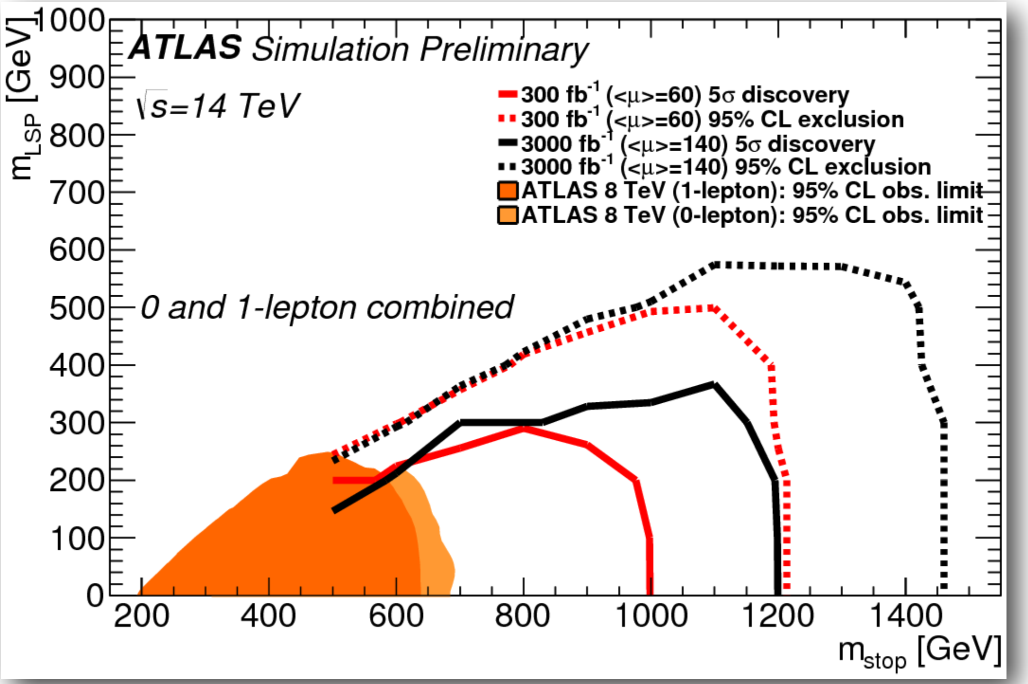
LHC/HL-LHC: stop





LHC/HL-LHC: stop





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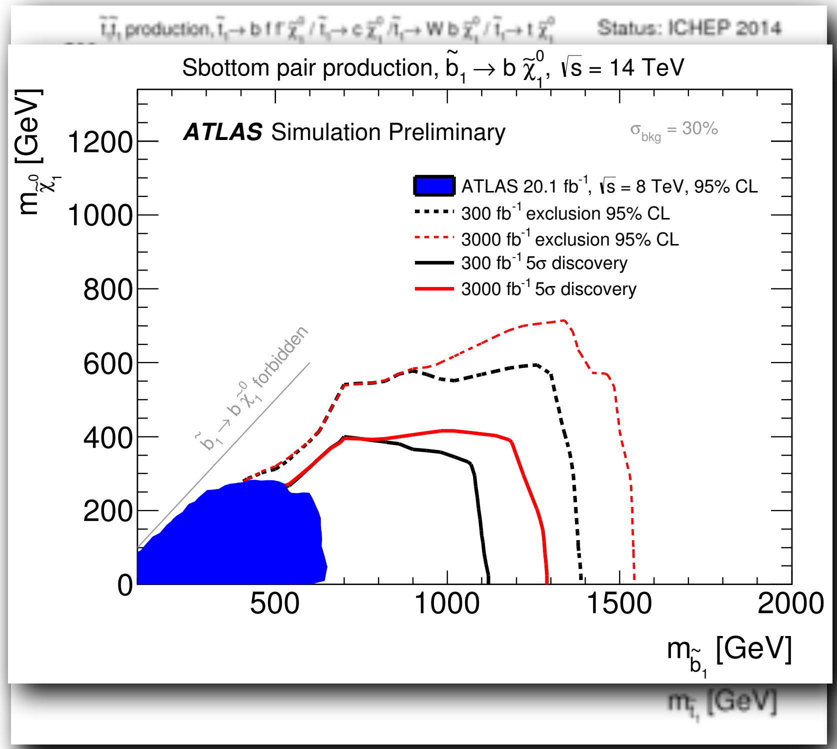
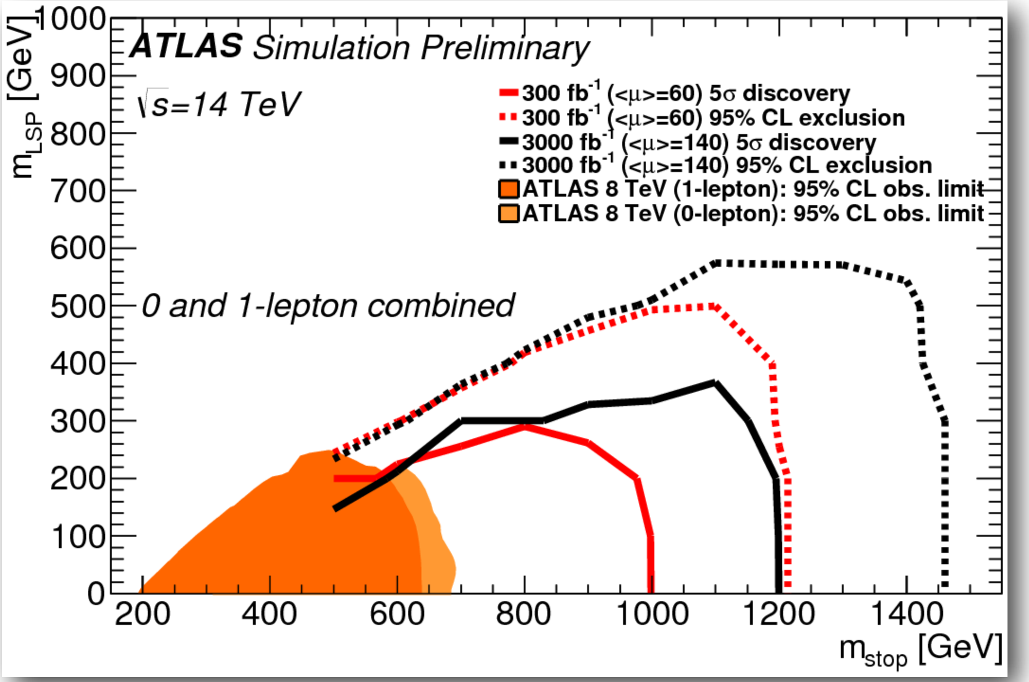




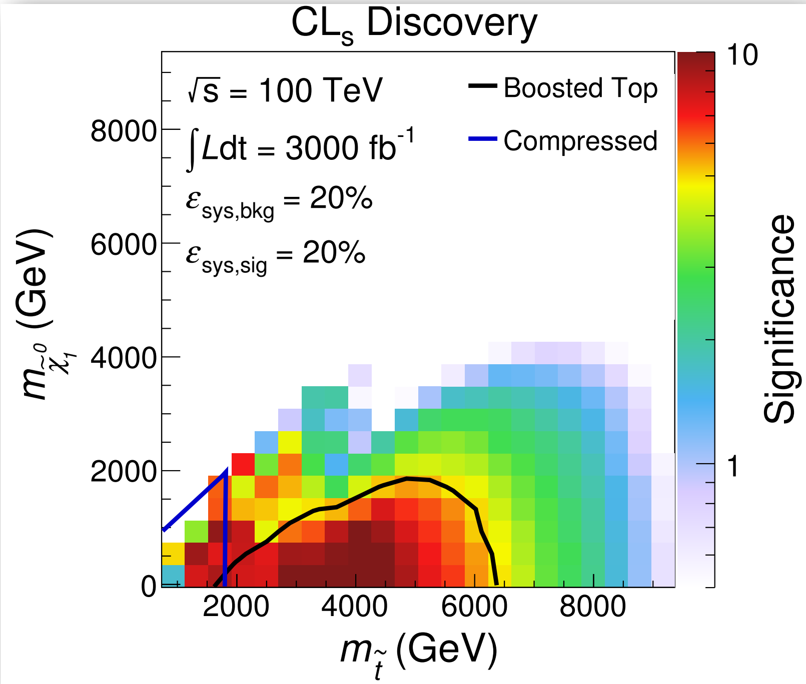
- Mass reach extended by a factor of 2 at 14 TeV, 300 fb^{-1}
- further extended by 20% at 3 ab^{-1}
- If no excess seen at 300 fb^{-1}, can not be seen at 3 ab^{-1}

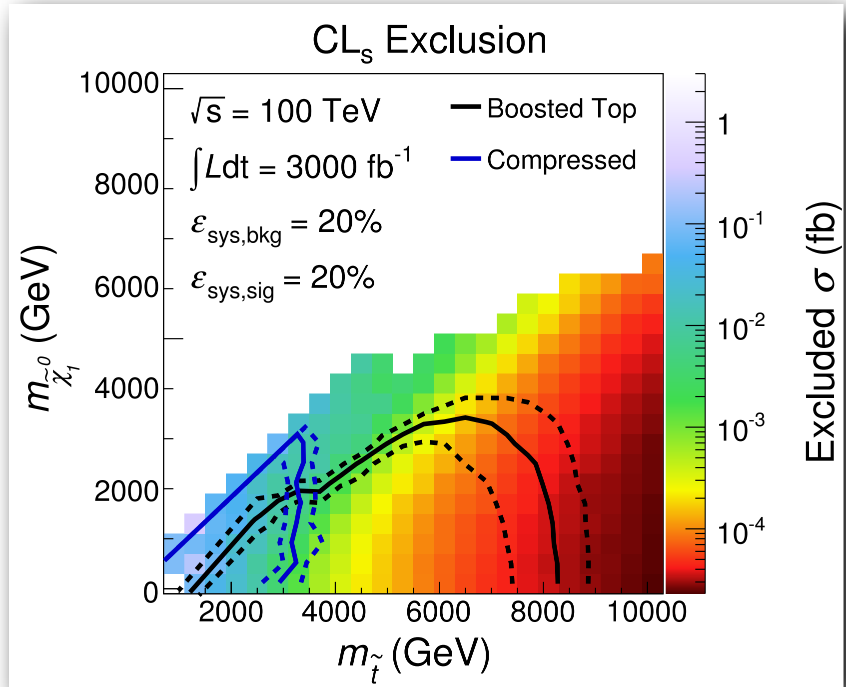
S. Su

True for many other new particle searches as well.

100 TeV pp: Stop

SUSY Colored production with gluinos and squarks
Mike Hance (LBNL)

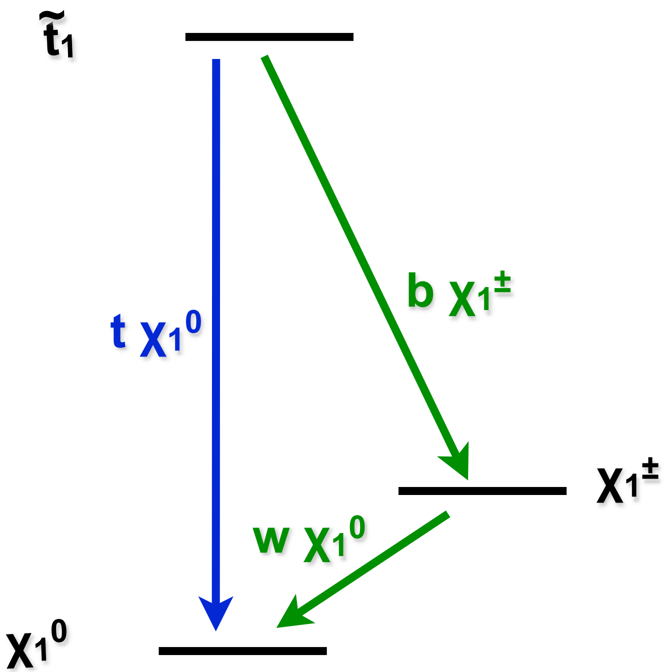




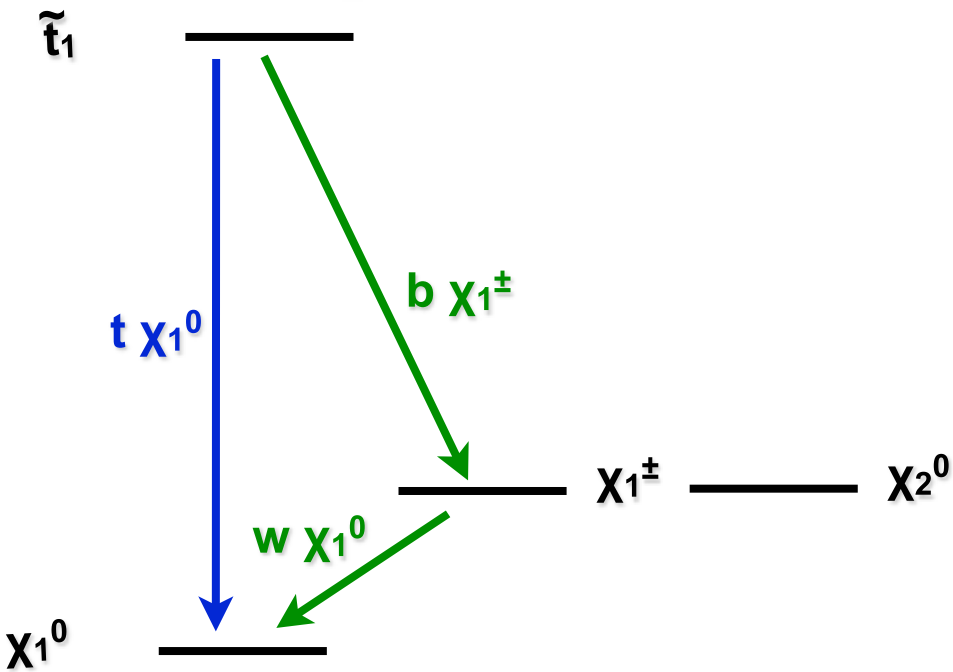
T. Cohen et. al, 1406.4512

- **HL-LHC: mass, coupling, decay channels, spin**
- **100 TeV pp: stop-stop-h production**
- **ILC: light stop < $E_{cm}/2$**

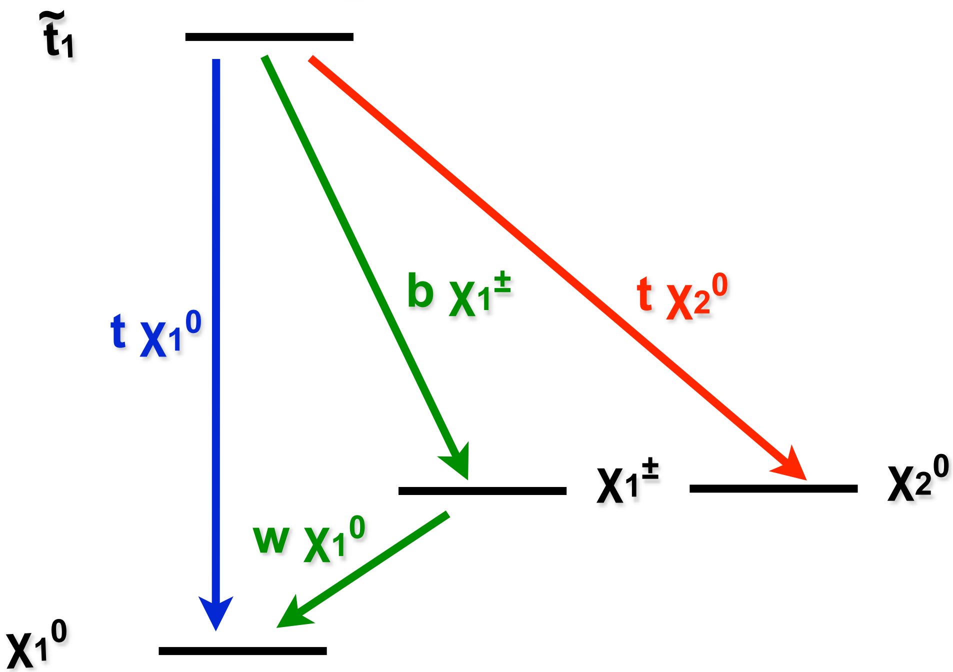
Stop decay



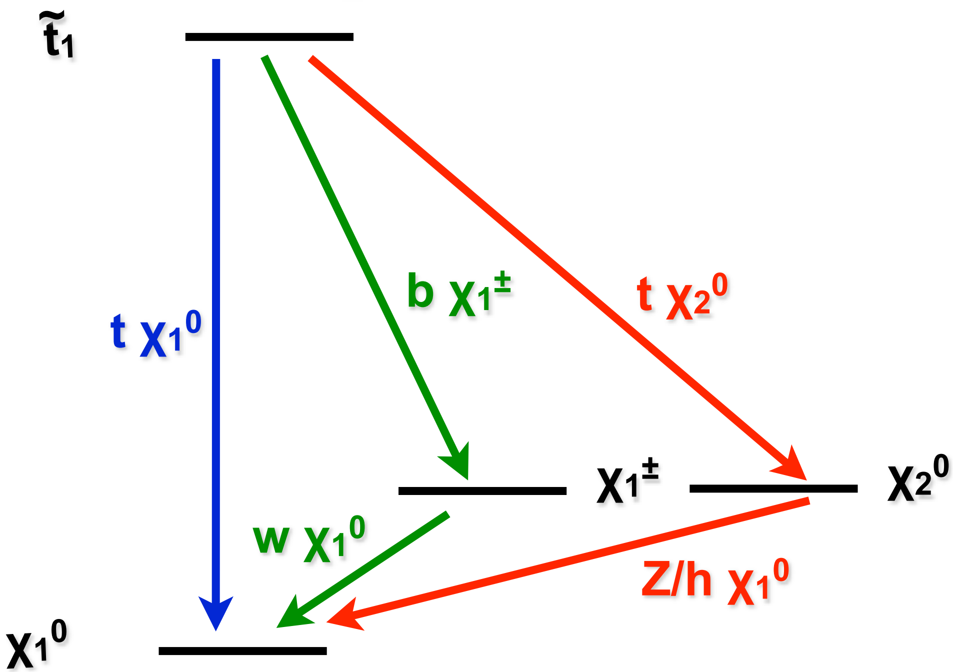
Stop decay



Stop decay

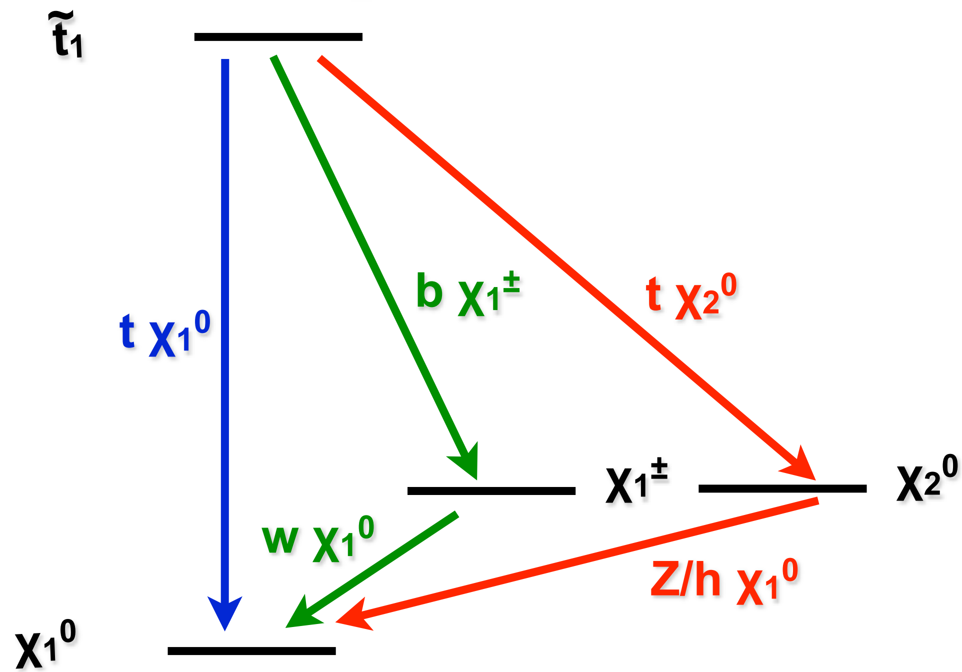


Stop decay



$\tilde{t}_1$
$t\ \chi_1^0$
$b\ \chi_1^\pm$
$t\ \chi_2^0$
$\chi_1^\pm$
χ_2^0
$w\ \chi_1^0$
$Z/h\ \chi_1^0$
χ_1^0

Stop decay

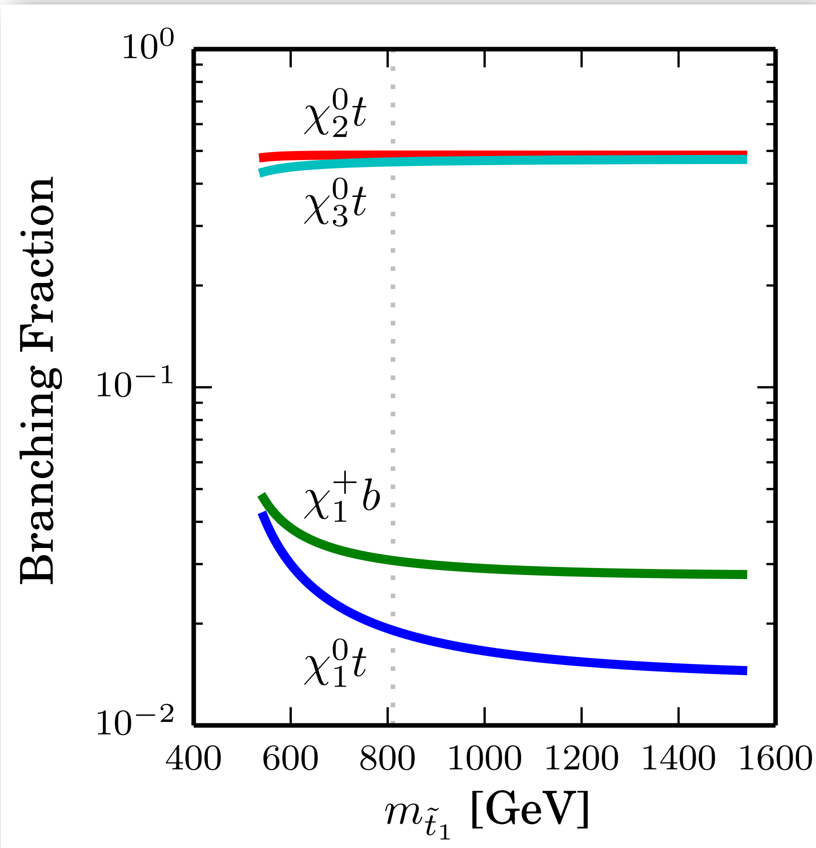


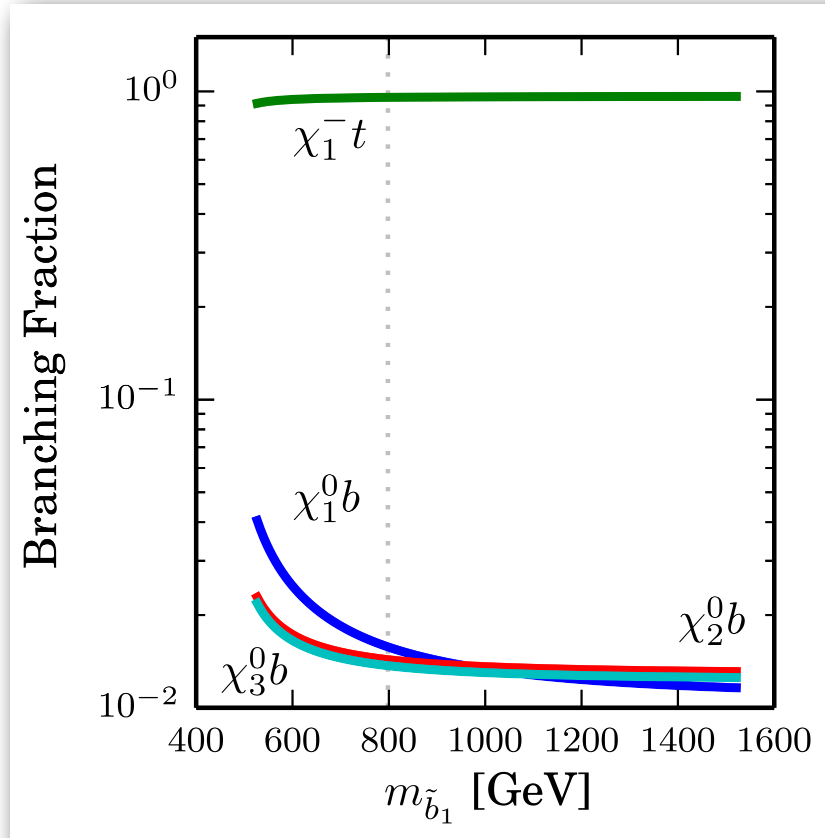
$t\ \chi_2^0$ could be competitive

- Current limit based on $t\ \chi_1^0$ and $b\ \chi_1^{\pm}$ become much weaker
- new final state for stop searches:
  (bW)(tZ/h)MET, (tZ/h)(tZ/h)MET

Stop decay

J. Eckel, SS, H. Zhang (2014)

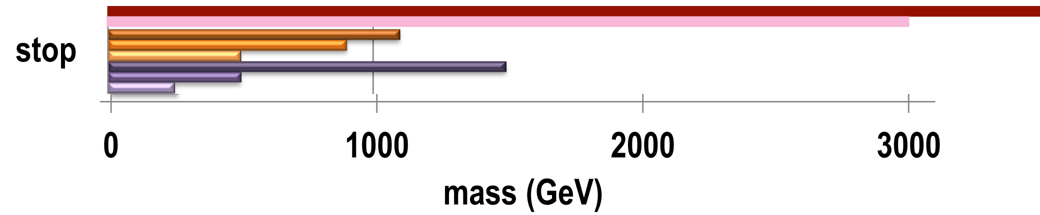




Higgsino NLSP, Bino LSP, left stop/sbottom

Naturalness

$$\epsilon \sim (125\ \mathrm{GeV}/M_{\mathrm{NP}})^2$$



- **LHC:** TeV scale for top partner, $\varepsilon \sim 1\%$
- **HL-LHC:**

  increase the reach by 10-20%, measure top partner property
- **100 TeV VLHC:** 10 TeV level, $\varepsilon \sim 10^{-4}$
- **ILC:** $E_{cm}/2$, 1 TeV machine, $\varepsilon \sim 1\%$

  Precision measurements, multi TeV level

SUSY and BSM Physics opportunities with higher energy proton colliders
Raman Sundrum (University of Maryland)

Dark Matter

$$m_{\mathrm{WIMP}} \leq 2\ \mathrm{TeV} \left(\frac{g_{\mathrm{eff}}^2}{0.3}\right)$$

Dark Matter, WIMPS or Axions
Prof. Liantao Wang (University of Chicago)
Vector boson productions associated with new physics
Prof. Bhaskar Dutta (Texas A&M University)

Effective operator

- study effective operators that couples DM to SM quarks/gluons
- same operator also contribute to DM direct detection: complementary

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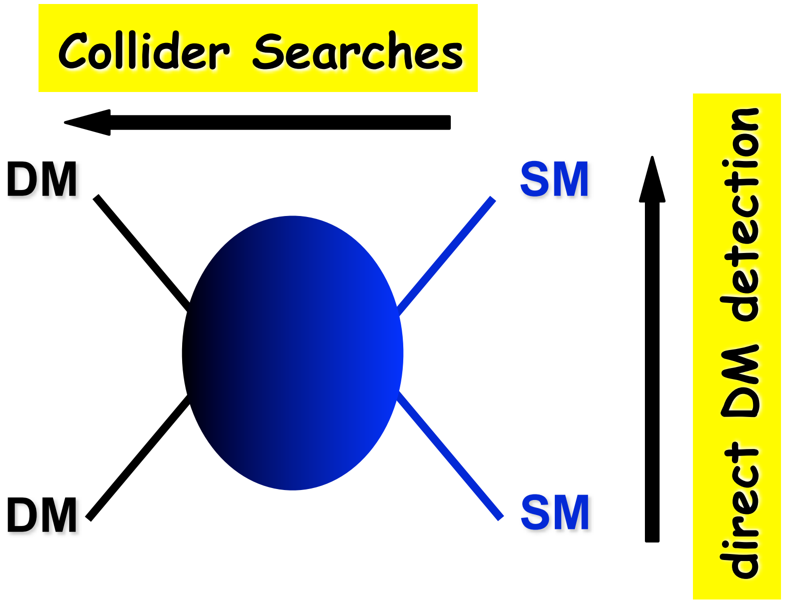
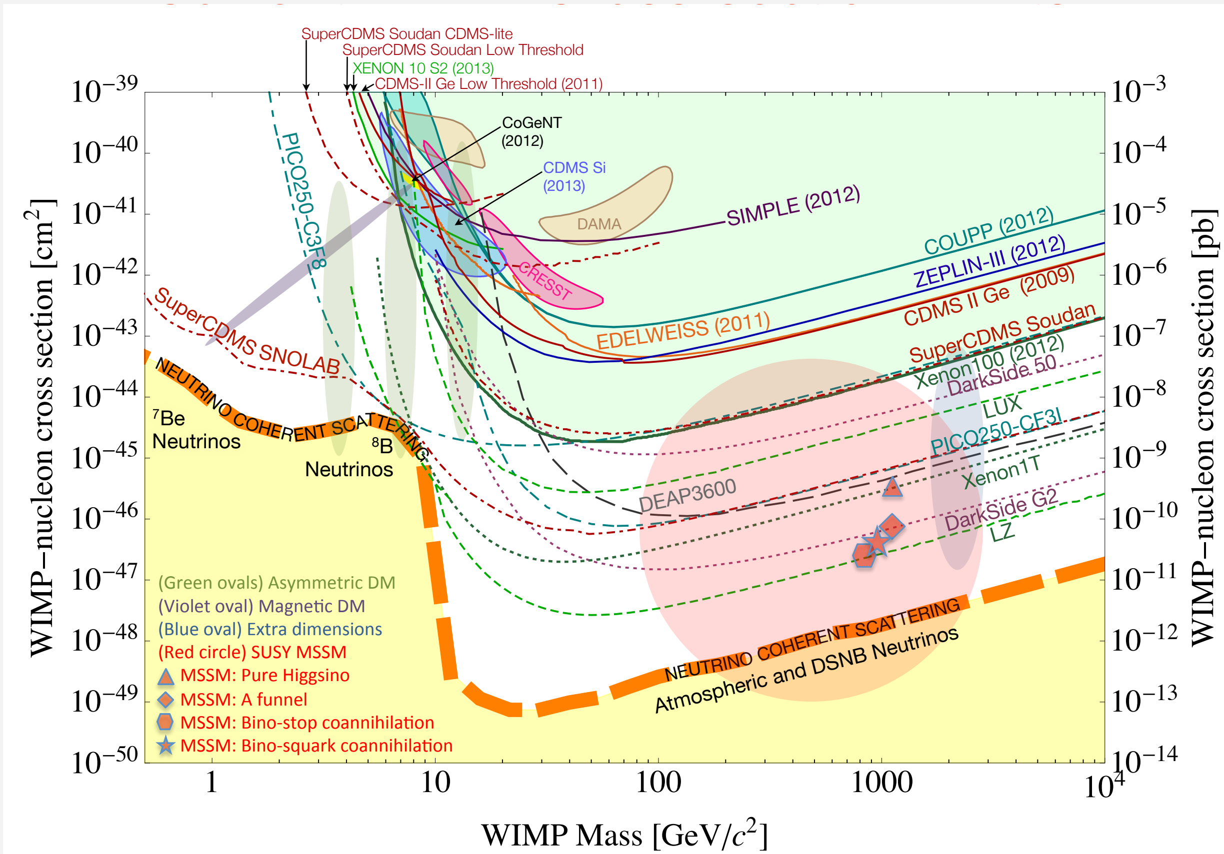


Direct detection versus collider reach

LUX collaboration, 2013



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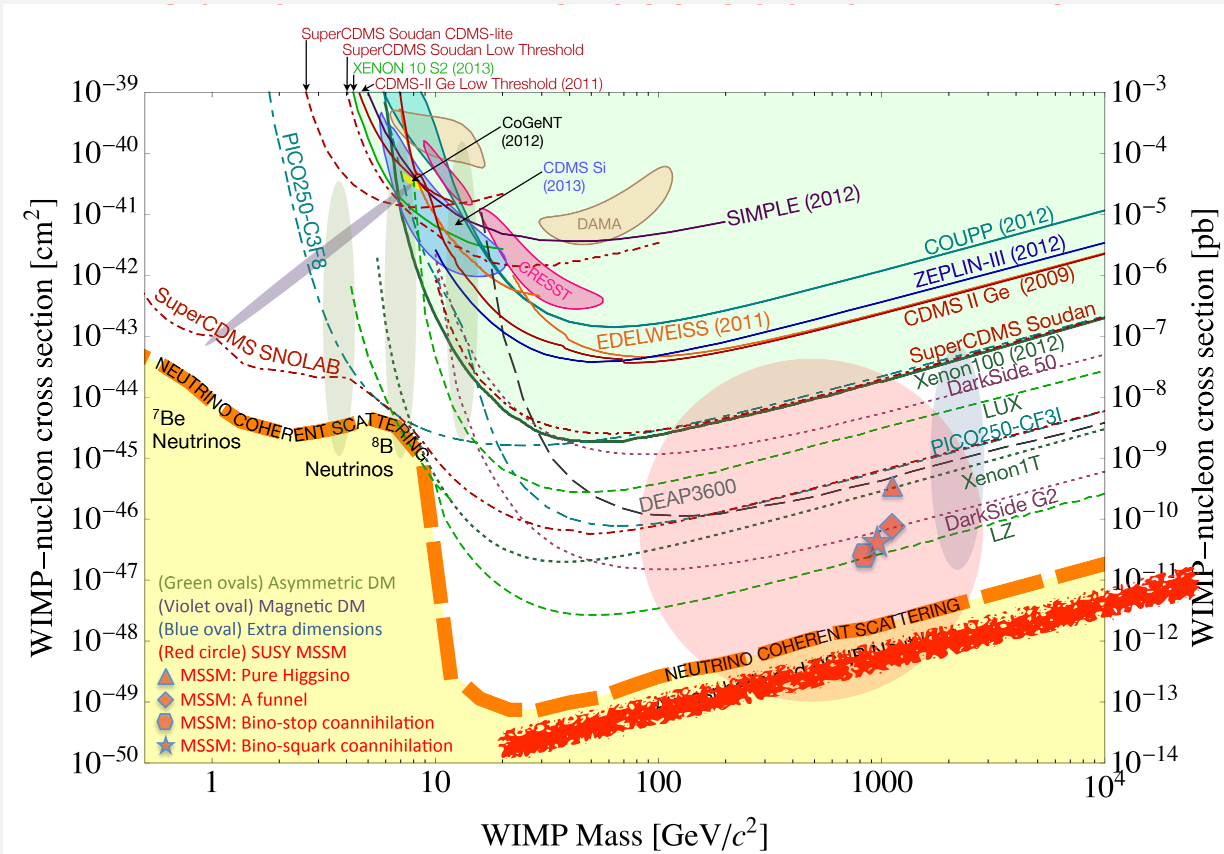

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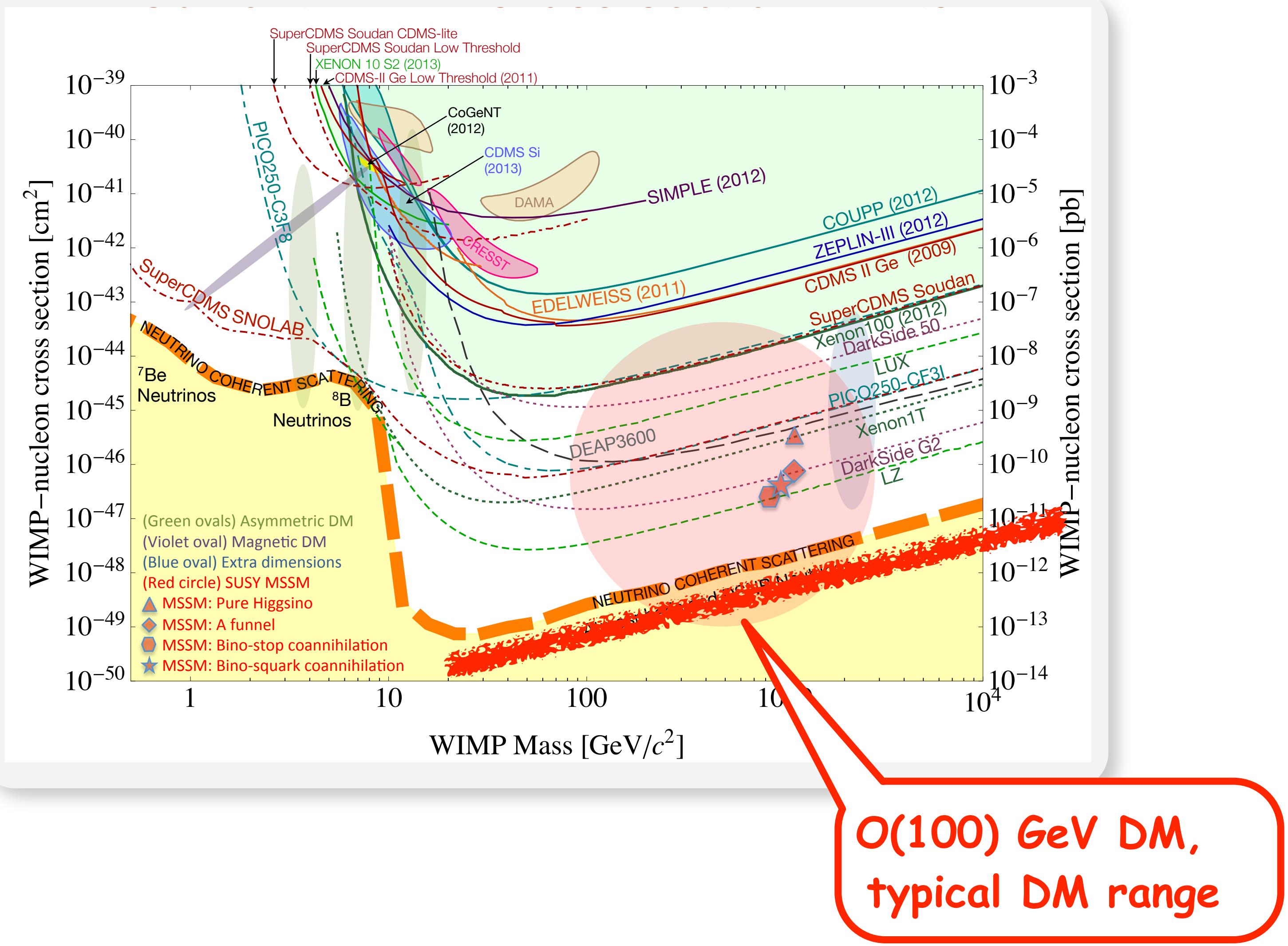
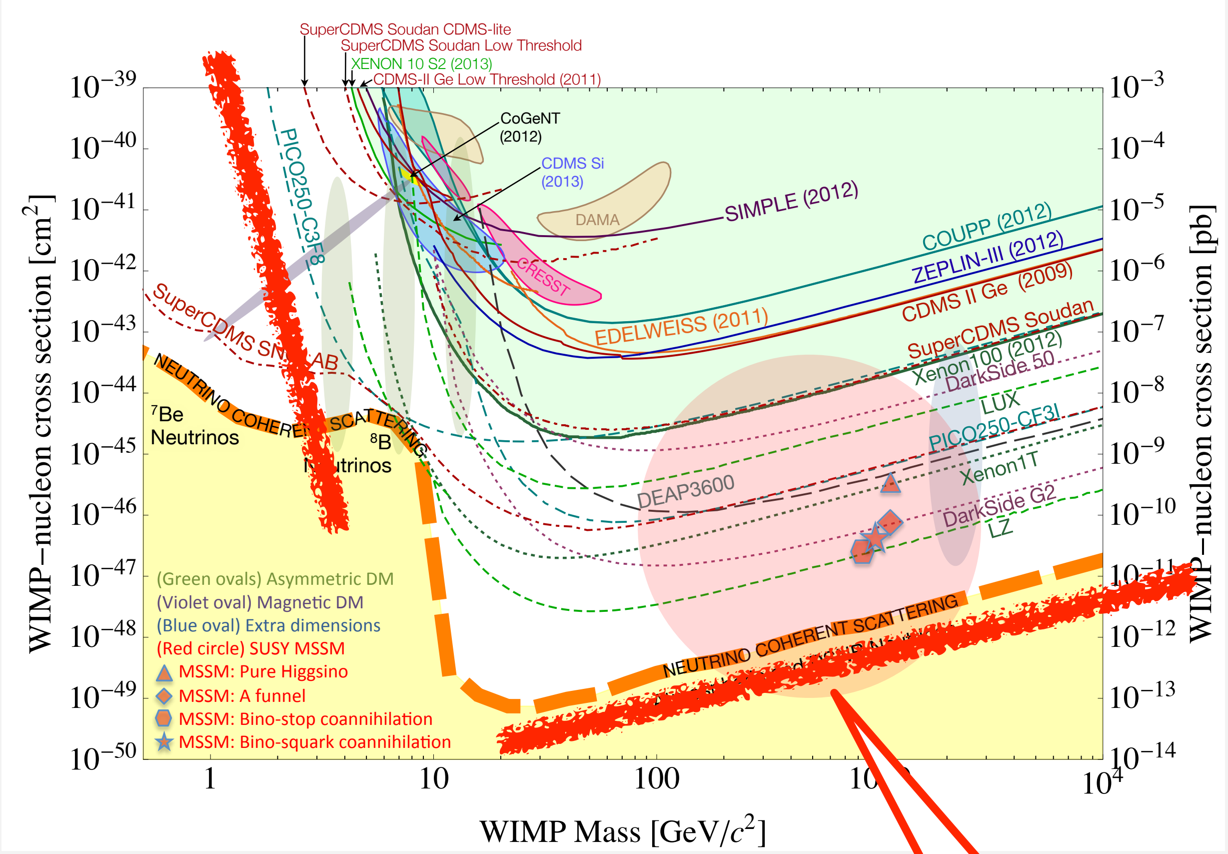


S. Su

Direct detection versus collider reach

LUX collaboration, 2013

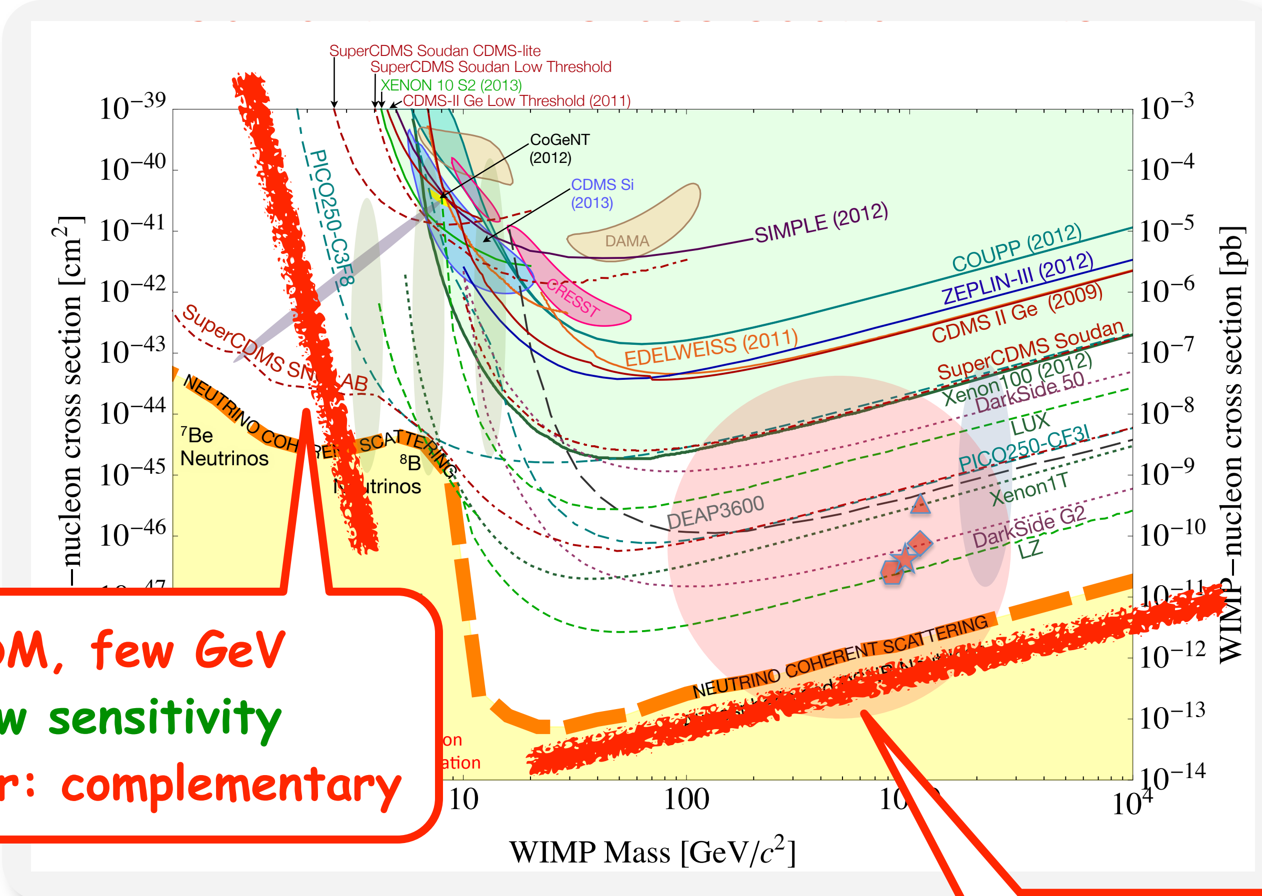


O(100) GeV DM, typical DM range

S. Su

Direct detection versus collider reach

LUX collaboration, 2013



light DM, few GeV
DD: low sensitivity
Collider: complementary

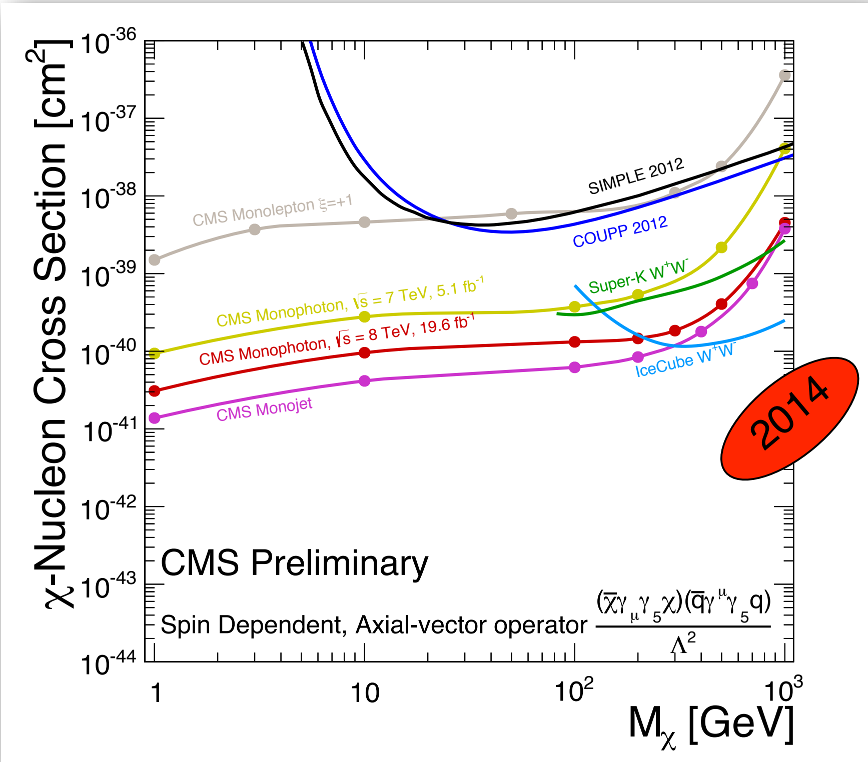
O(100) GeV DM,
typical DM range

S. Su

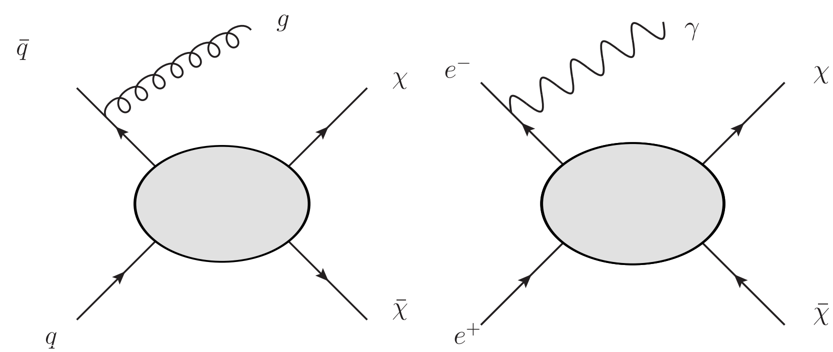
LHC/100 TeV: Higgs

SUSY and BSM Highlights from the LHC
James PILCHER (University of Chicago)

Dark Matter, WIMPS or Axions
Prof. Liantao Wang (University of Chicago)



CMS PAS EXO-12-047



monojet, monophoton, monoZ, monoW, mono-b,...

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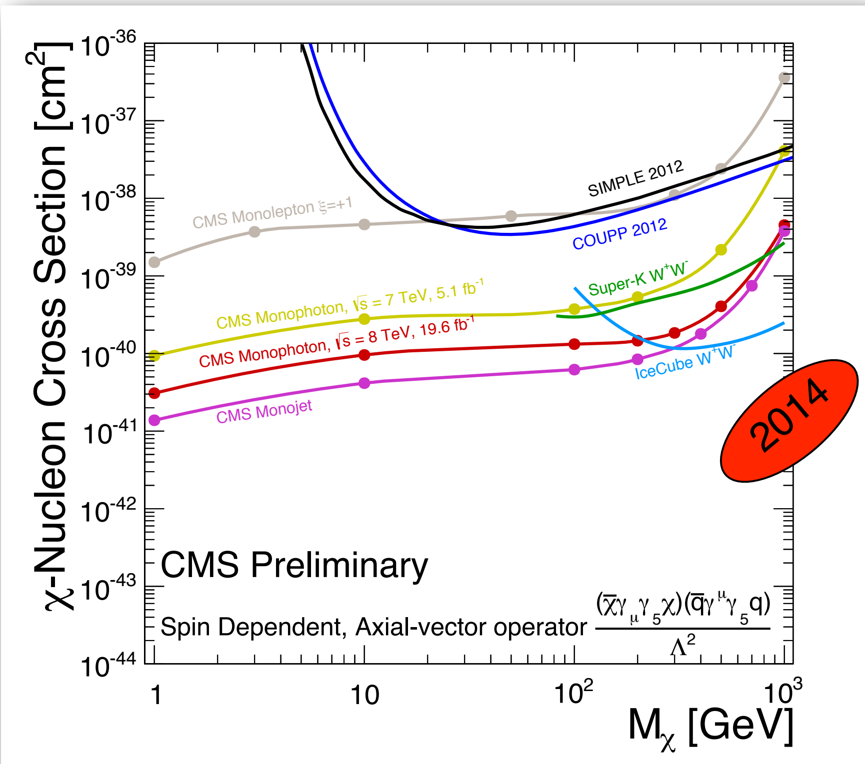

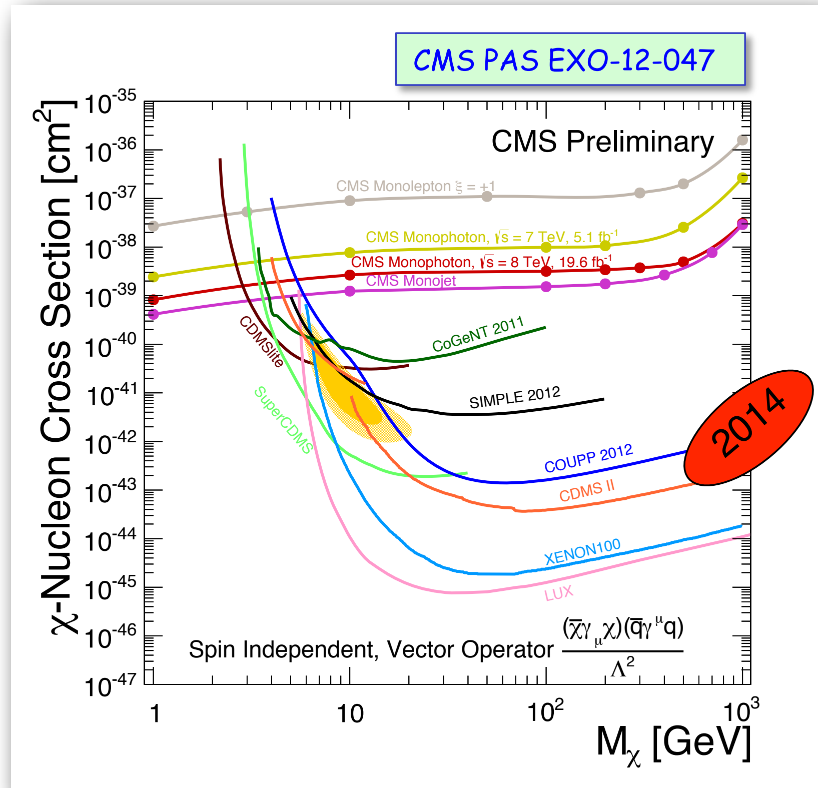

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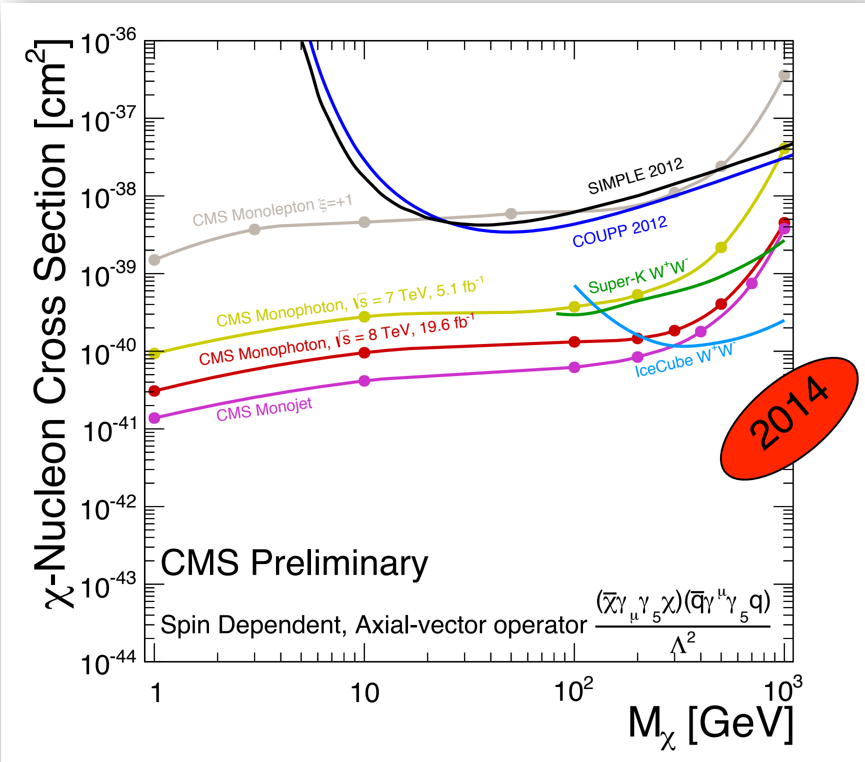

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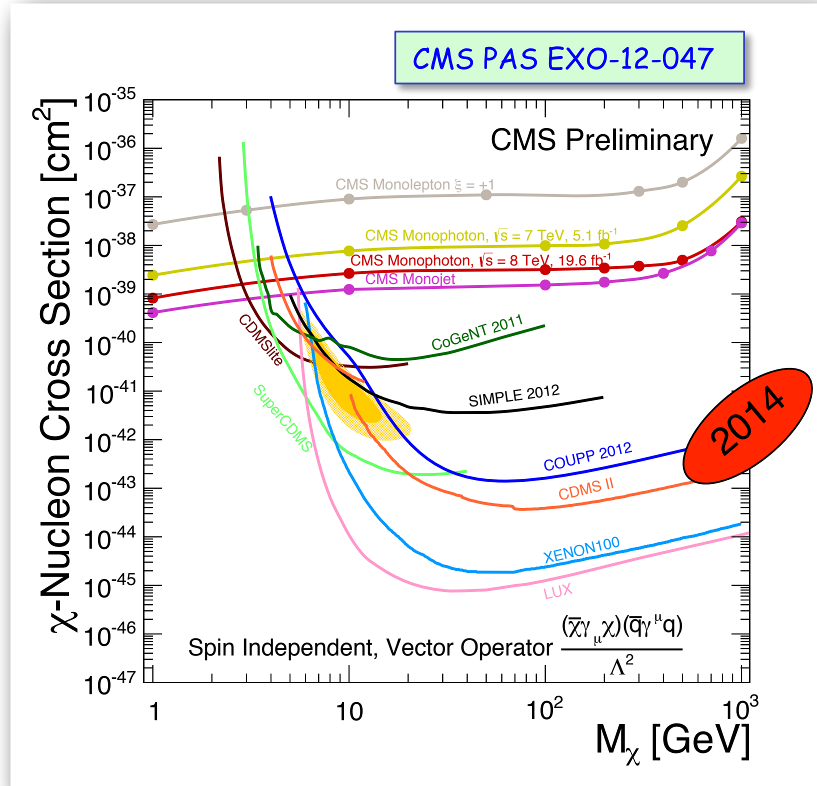

Collider better:
small mx region, spin-dependent

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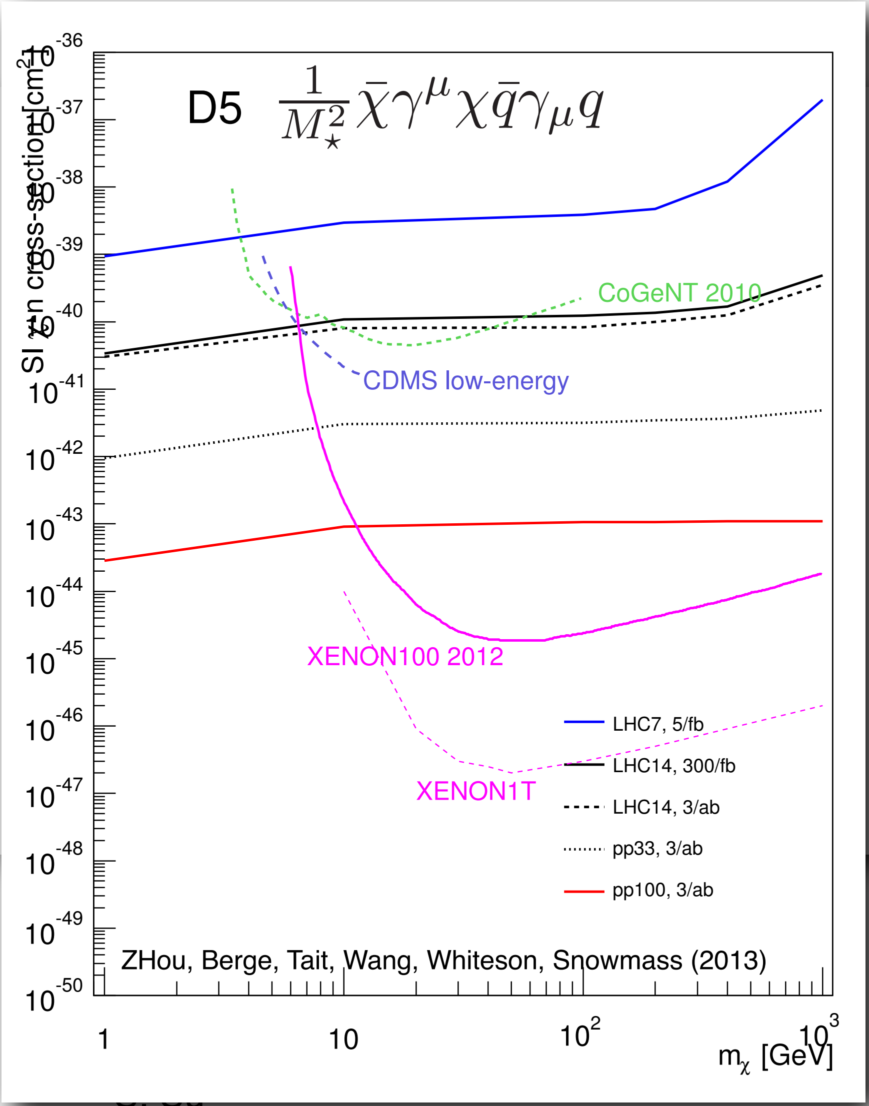
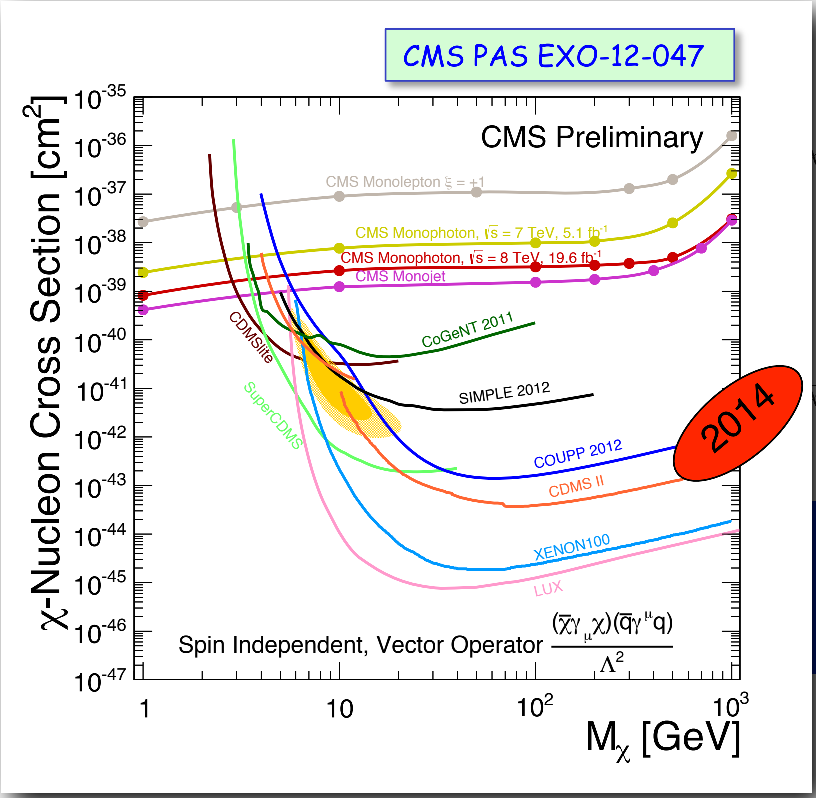
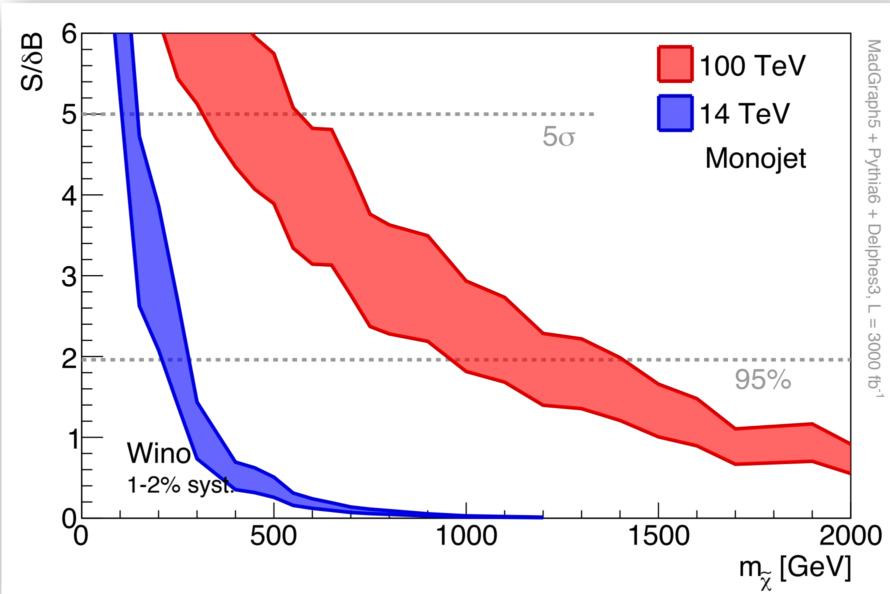




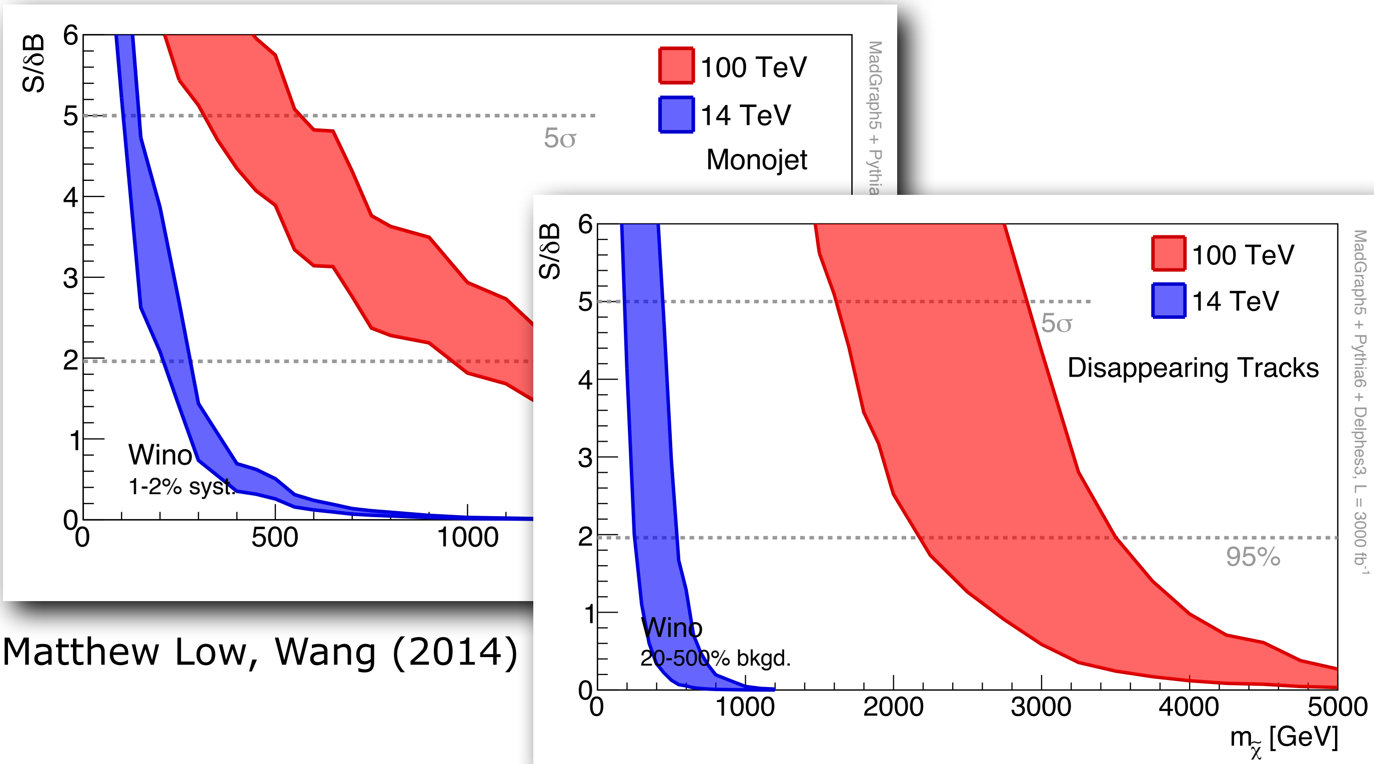
Collider better:
small m_χ region, spin-dependent

LHC/100 TeV: MSSM DM



Matthew Low, Wang (2014)

LHC/100 TeV: MSSM DM



Matthew Low, Wang (2014)

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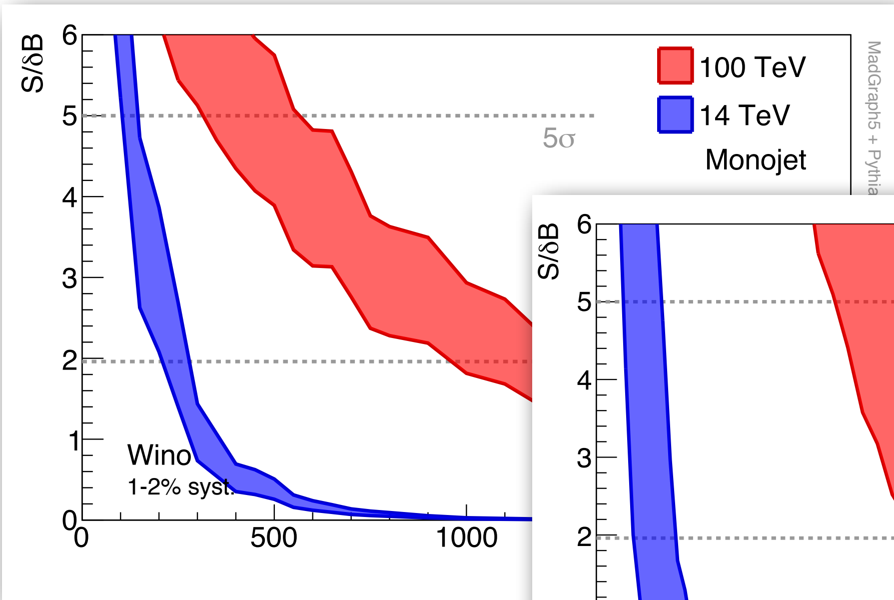
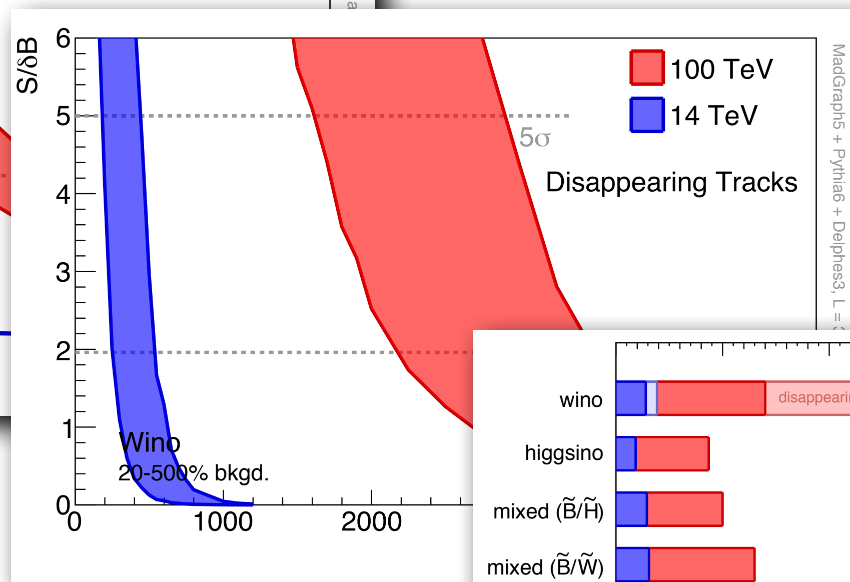
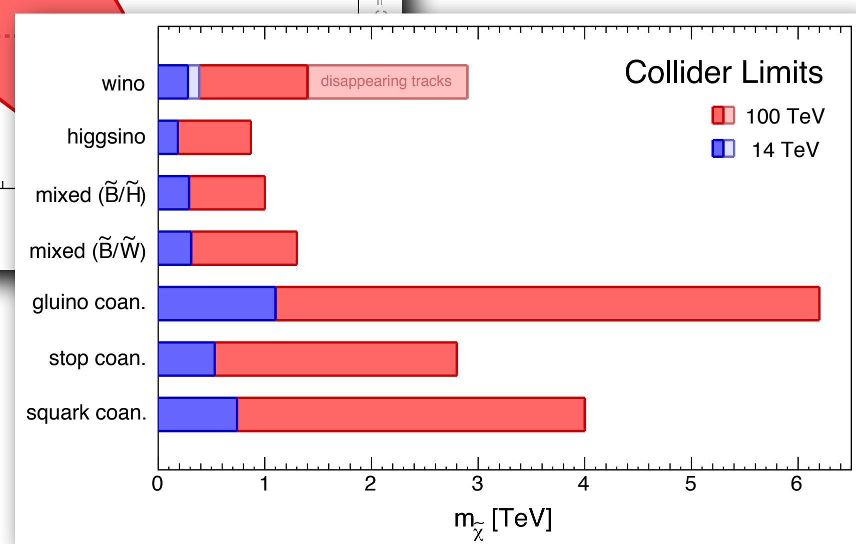


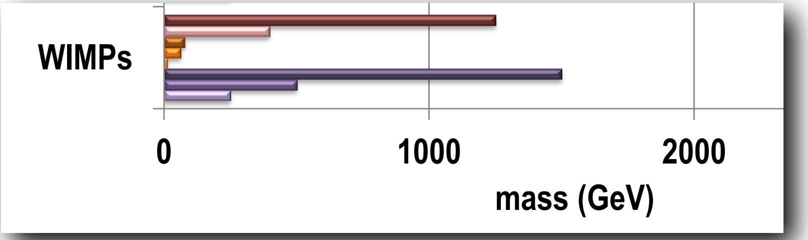




Matthew Low, Wang (2014)

Dark Matter

$$m_{\mathrm{WIMP}} \leq 2\ \mathrm{TeV}\left(\frac{g_{\mathrm{eff}}^2}{0.3}\right)$$



- Dark matter at TeV scale (Wino or Higgsino LSP)
  - ➡ can not be explored at LHC 14 with 300 fb^{-1}
  - ➡ enhanced reach at VLHC 33 or 100 TeV
- Smaller dark matter mass
  - ➡ low mass loopholes of suppressed coupling or compressed spectrum, small MET
  - ➡ e+e- collider, reach $E_{cm}/2$.

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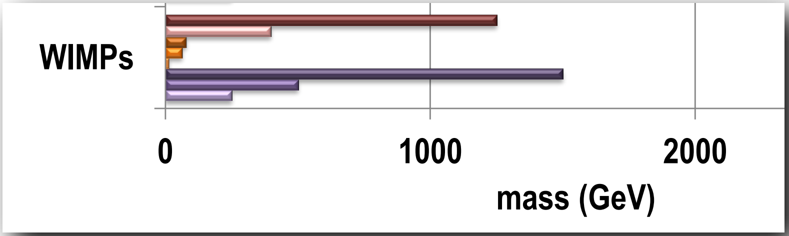

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SUSY Electrowinos including Higgs in the final state
Felix Kling (University of Arizona)
Dark Matter, WIMPS or Axions
Prof. Liantao Wang (University of Chicago)
Vector boson productions associated with new physics (VBF)
Prof. Bhaskar Dutta (Texas A&M University)

Searches for New Particles

Searches for New Particles

- strong interacting particles

  gluinos, squarks

- EW interacting particles

  electroweakinos: (W/Z/h)(W/Z/h)+MET final states

  sleptons: reach depends on LSP type

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High-mass states decaying to ttbar in fully boosted regime at a 100 TeV collider
Sergei Chekanov (ANL)
Ratios and characteristic distributions in the search for deviation from the SM productions, Dr. David Curtin (Stony Brook)
Colored resonances, Dr. Felix Yu (Fermilab)
Boosted SM topologies and algorithms, Brock Tweedie (University of Pittsburgh)
Composite Higgs, Giuliano Panico (CERN & ETH Zurich)
Zprime at 100 TeV Collider, Zhen Liu (University of Pittsburgh)
SUSY and BSM Highlights from the LHC, James PILCHER (University of Chicago)
Prospects of New Physics searches using HL-LHC, Altan Cakir (DESY)

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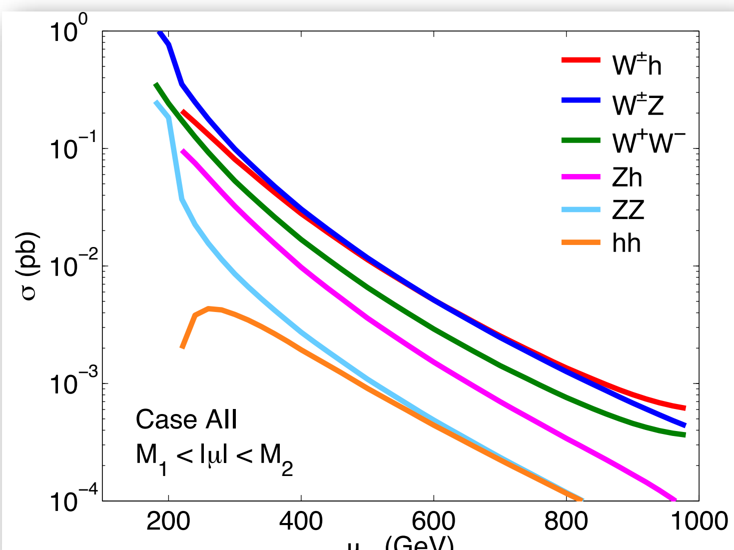

r in fully boosted regime at a 100 TeV collider

ions in the search for deviation from the SM

Brook)

rmilab)

hms, Brock Tweedie (University of Pittsburgh)

ERN & ETH Zurich)

iu (University of Pittsburgh)

e LHC, James PILCHER (University of Chicago)

s using HL-LHC, Altan Cakir (DESY)

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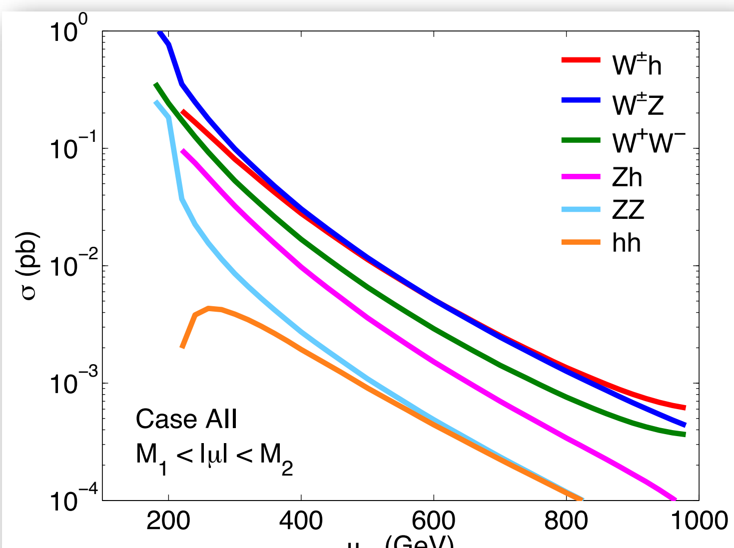
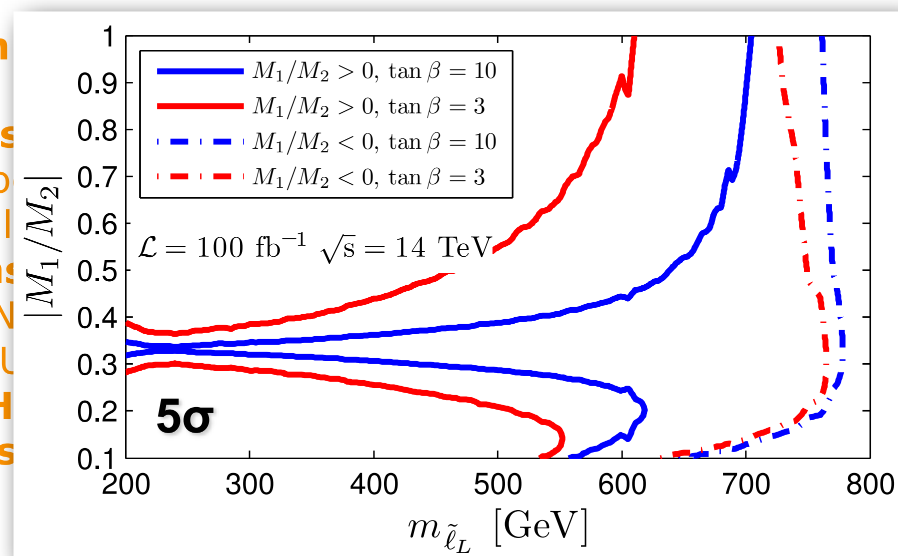
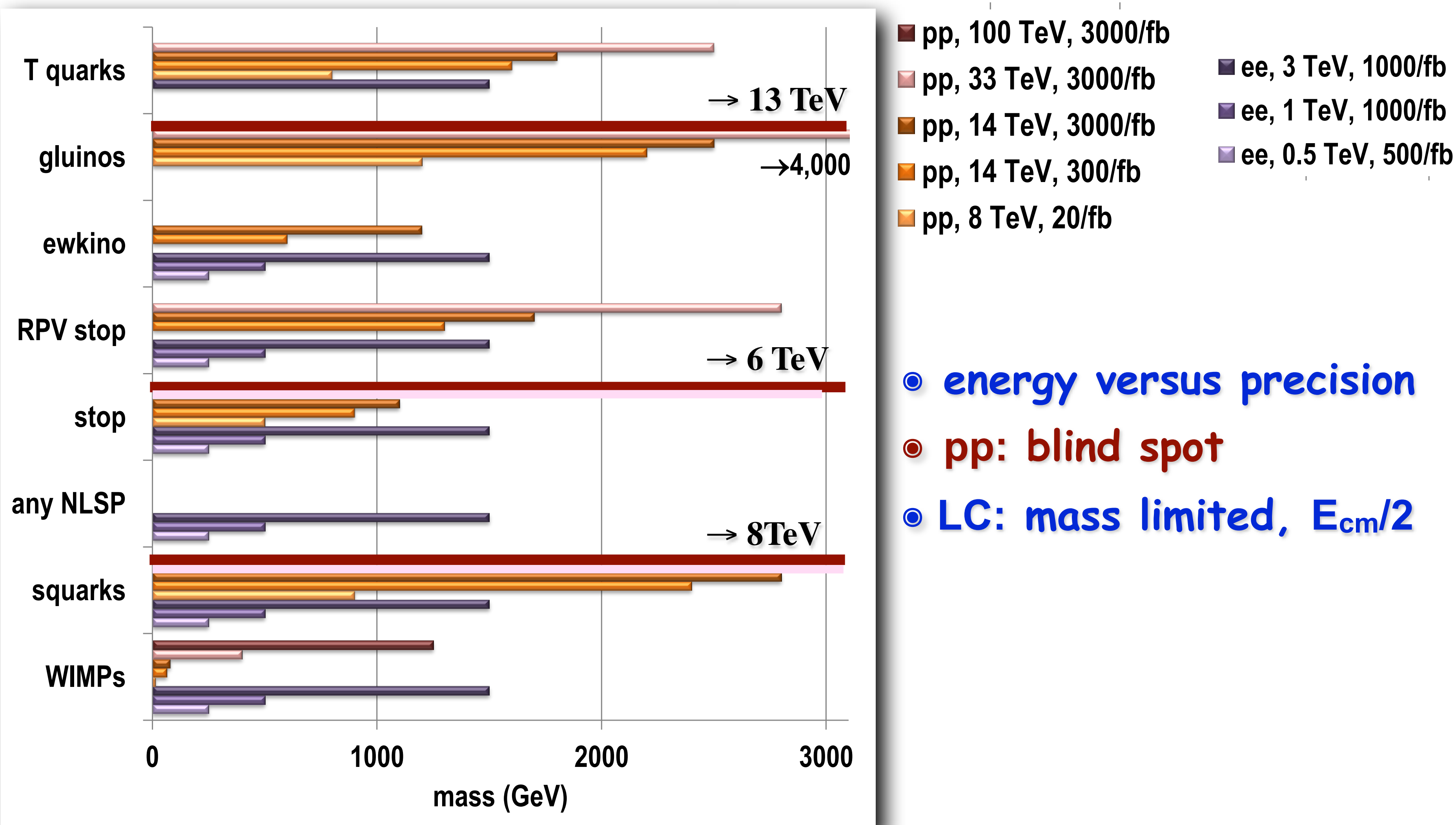
Eckel, Ramsey-Musolf, Shepherd, Su (2014)





BSM: Collider Reach



- energy versus precision
- pp: blind spot
- LC: mass limited, $E_{cm}/2$

S. Su

Snowmass new physics working group report

Cosmo connection

baryongenesis, phase transition

Electroweak baryogenesis, Patrick Meade (Stony Brook)

Conclusion

- the discovery of Higgs is a remarkable triumph in particle physics
- a light weakly coupled Higgs argues for new physics beyond SM
- Search for new physics calls for both high precision machine and high energy machine
- HL-LHC: probe Higgs precision few% (factor of 2 increase), search for new physics limited (20% increase)
- 100 TeV pp machine:
  - probe energy frontier: BSM Higgs, naturalness connection, dark matter
  - precision, H coupling, H^3,H^4,V^3,V^4 couplings (cosmo connection)
- FCC-ee/hh, CEPC/SPPC, ILC/CLIC...

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An exciting journey ahead of us!

Conclusion

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LHC

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HL-LHC

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Conclusion

LHC

HL-LHC

100 TeV pp

An exciting journey ahead of us!

Conclusion

LHC

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100 TeV pp

Lepton Collider

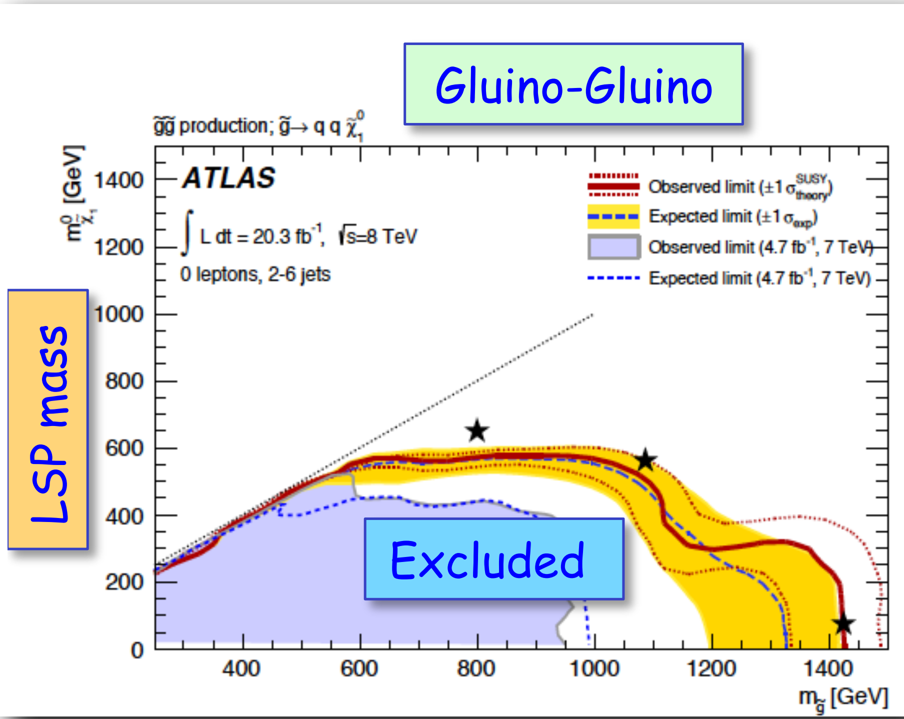
An exciting journey ahead of us!

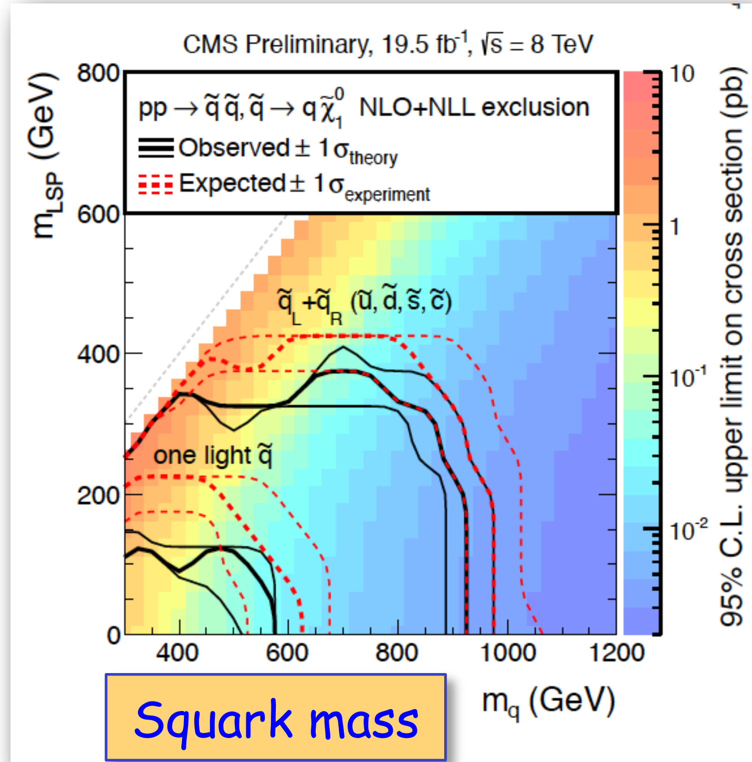
BACKUP

Gluinos and Squarks

LHC (now): BSM

SUSY and BSM Highlights from the LHC
James PILCHER (University of Chicago)





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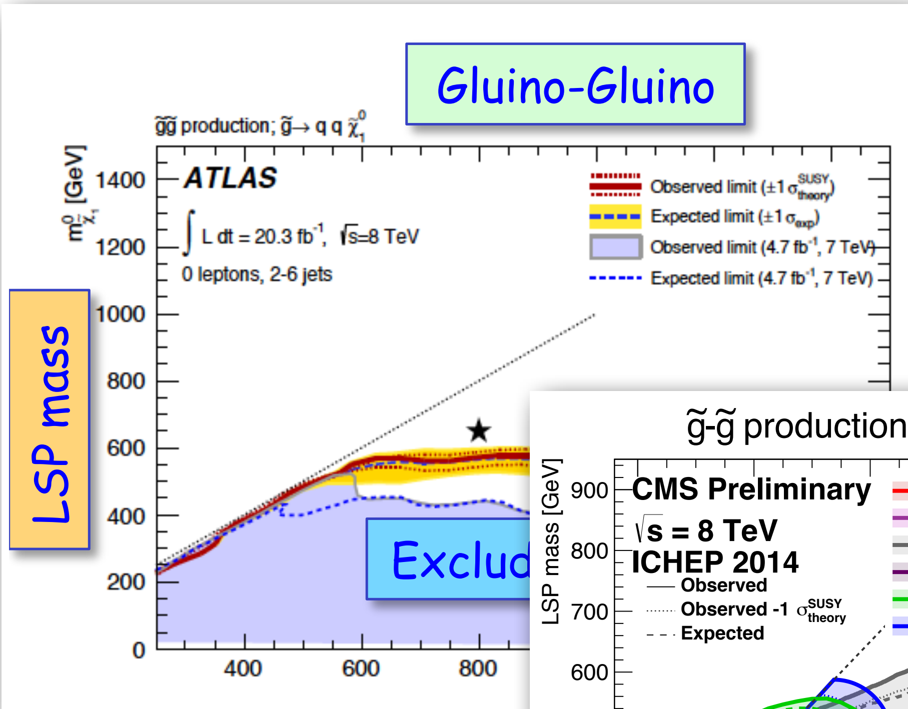
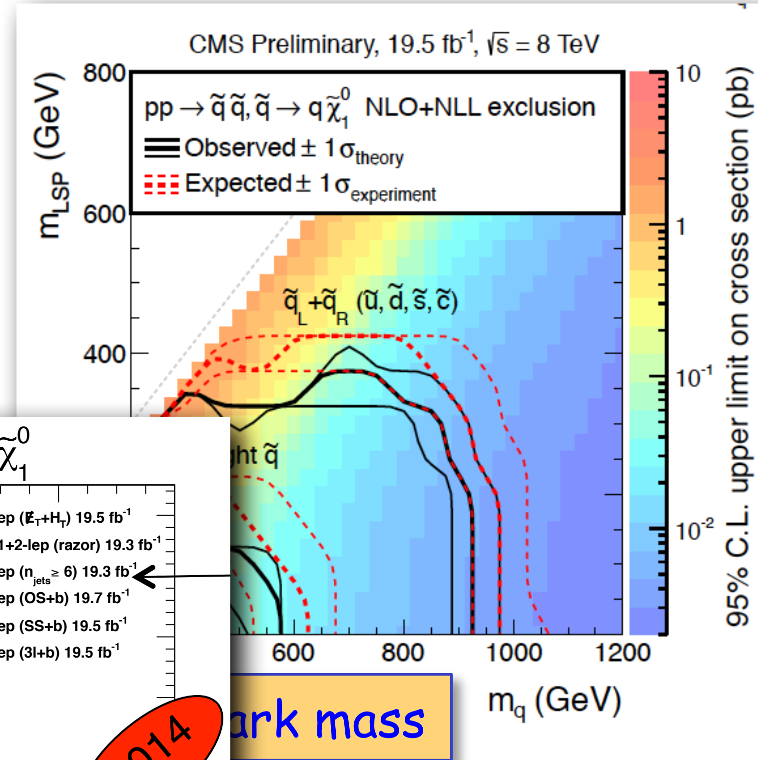
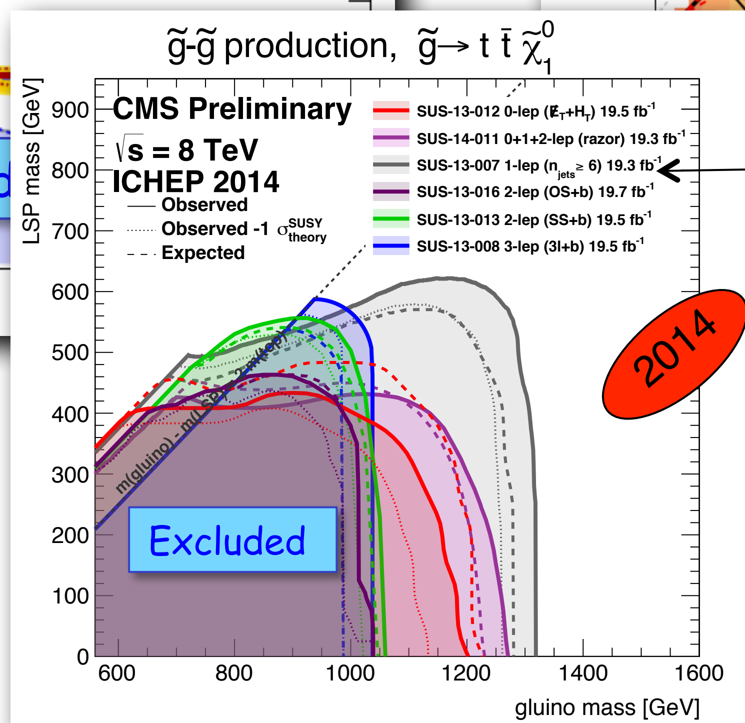
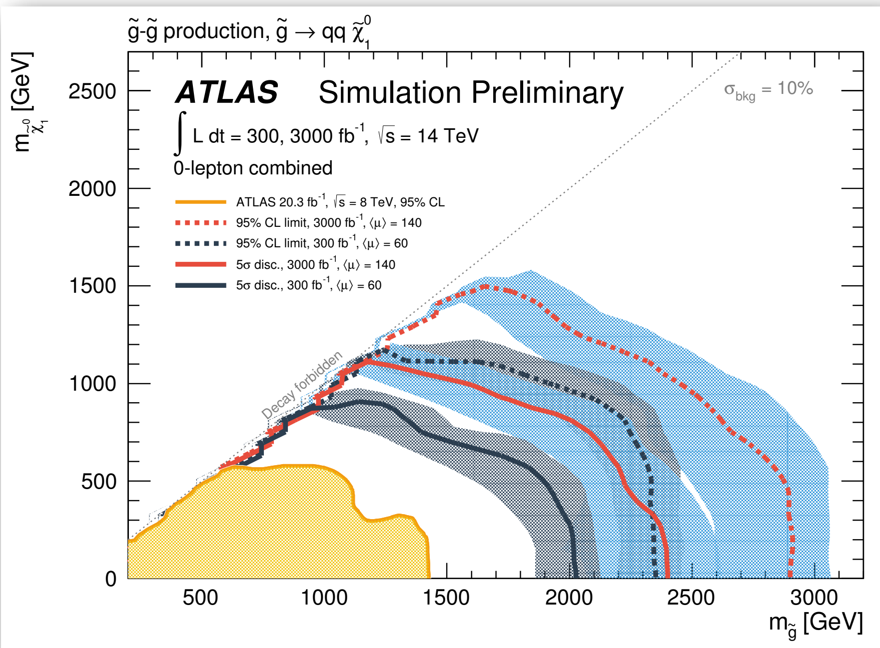


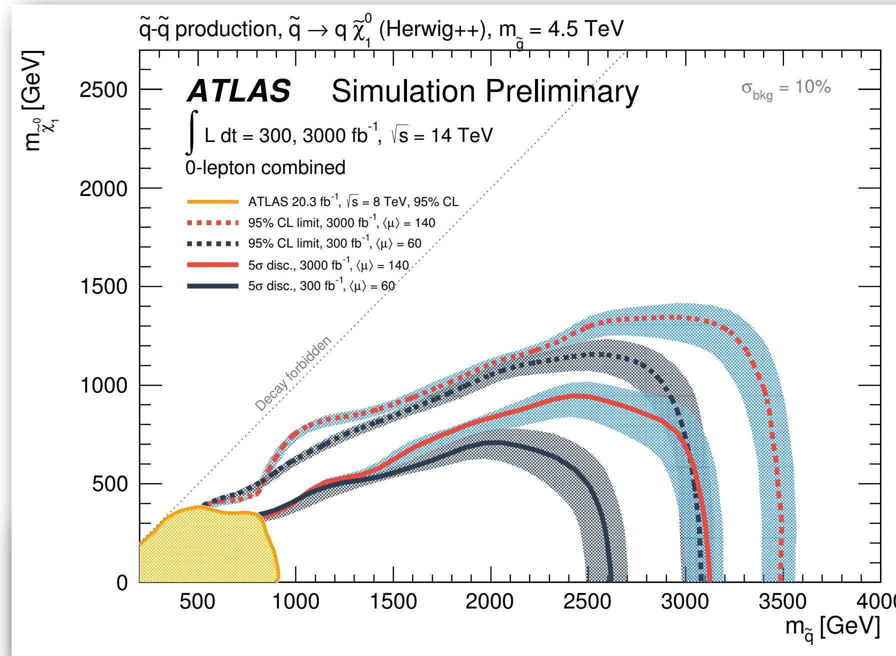


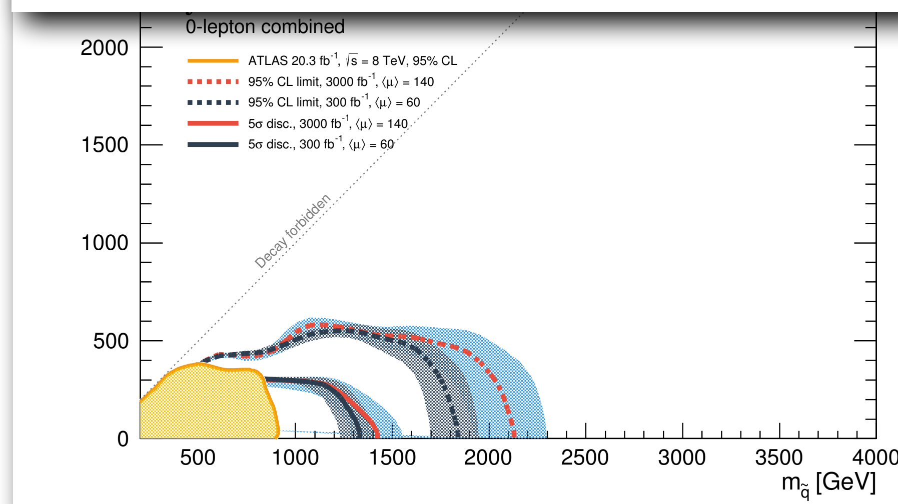


LHC/HL-LHC: *gluino and suark*

SUSY Colored production with gluinos and squarks, Mike Hance (LBNL)







ATLAS-PUB-2014-010

S. Su

LHC/HL-LHC: gluino and suark

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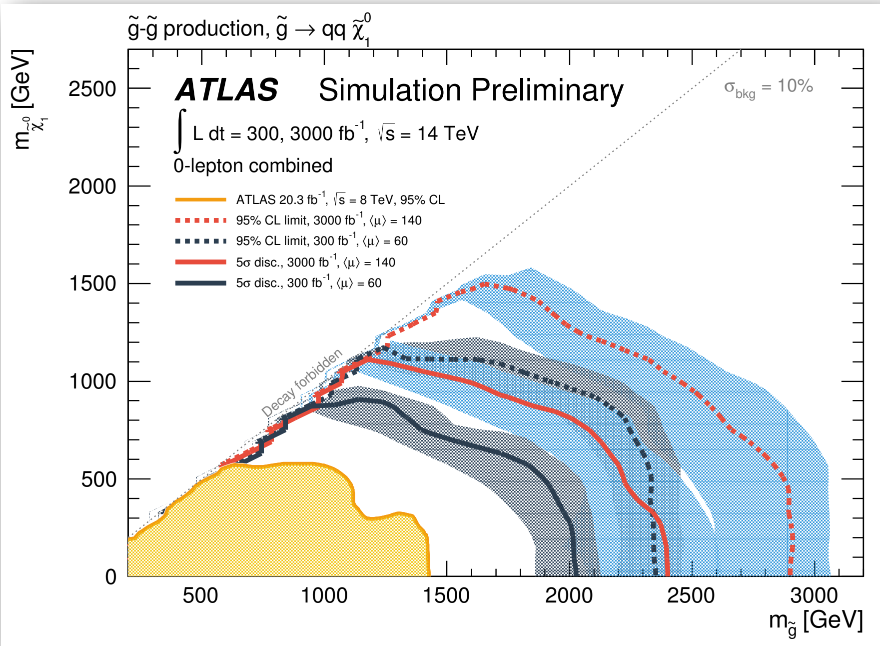

ATLAS-PUB-2014-010

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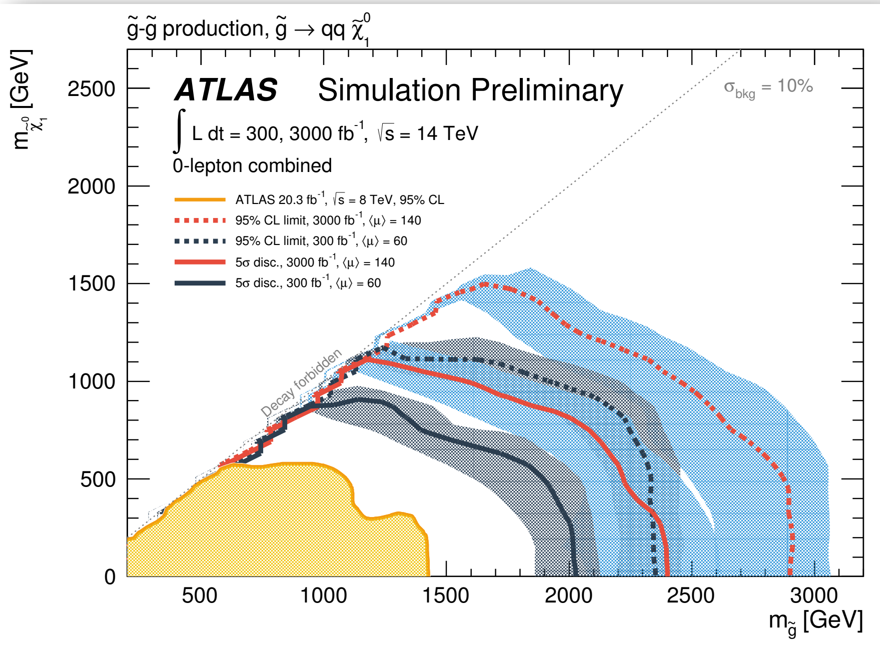

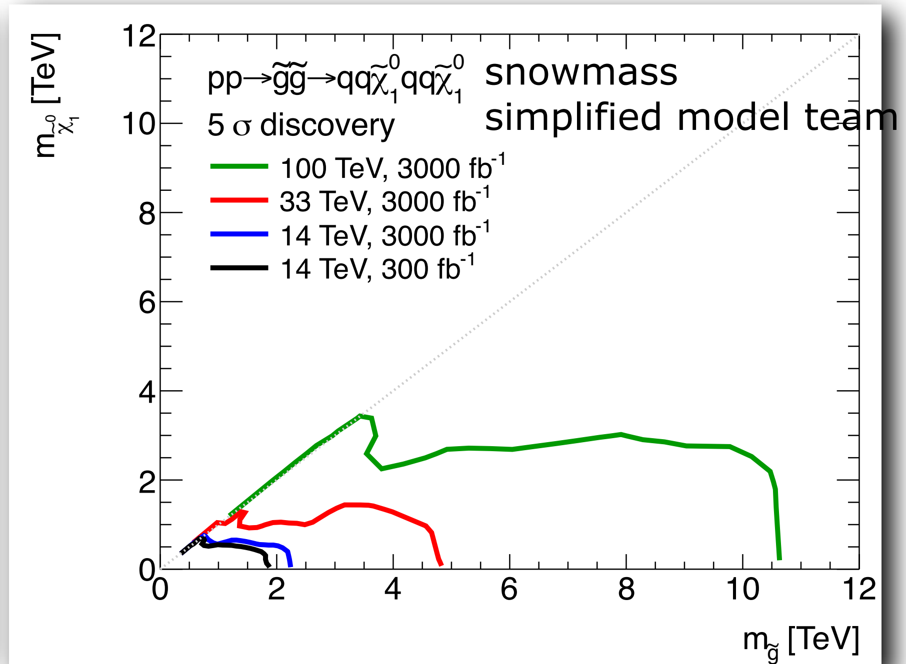

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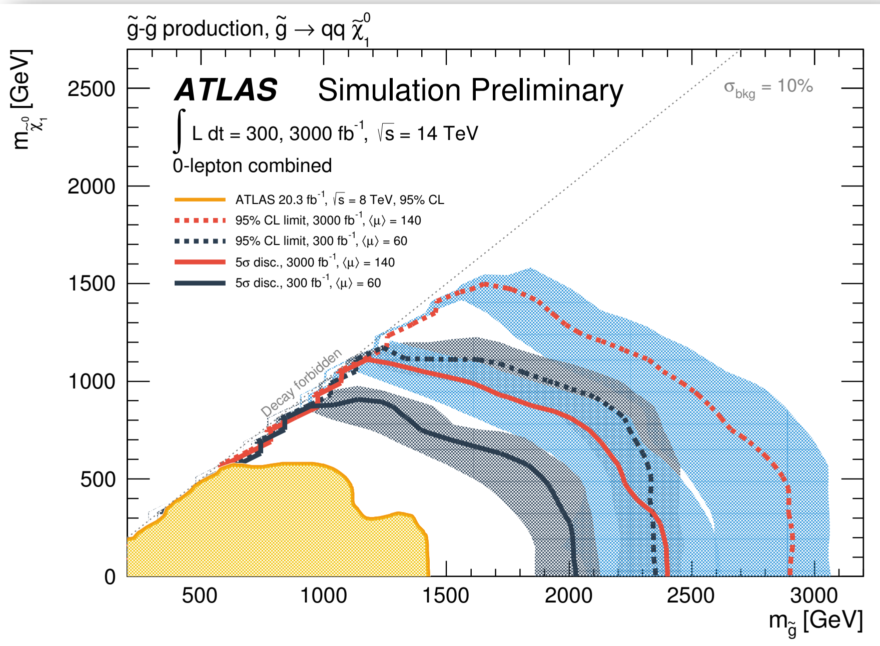
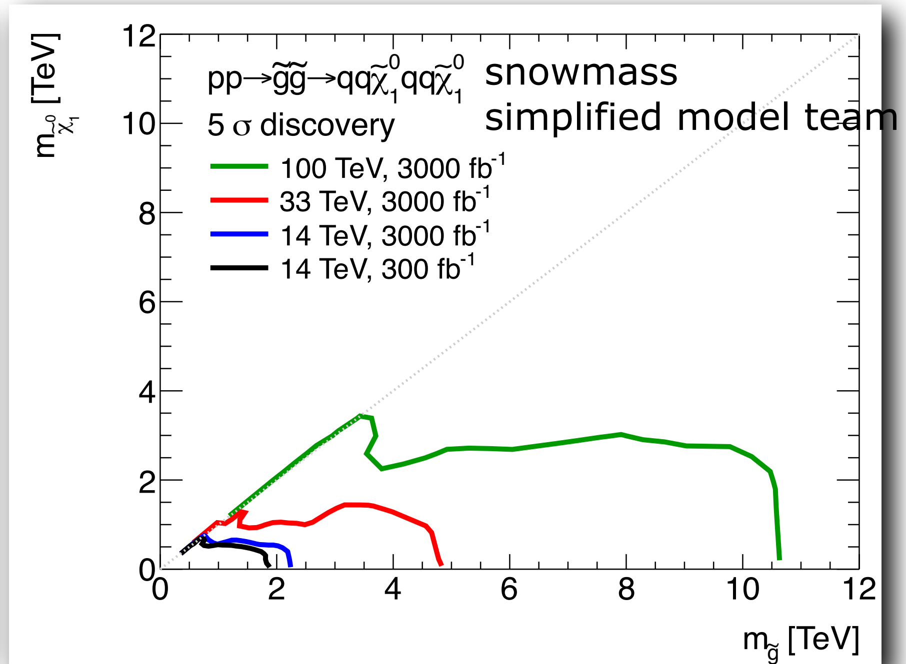
LHC/HL-LHC: gluino and suark

SUSY Colored production with gluinos and squarks, Mike Hance (LBNL)





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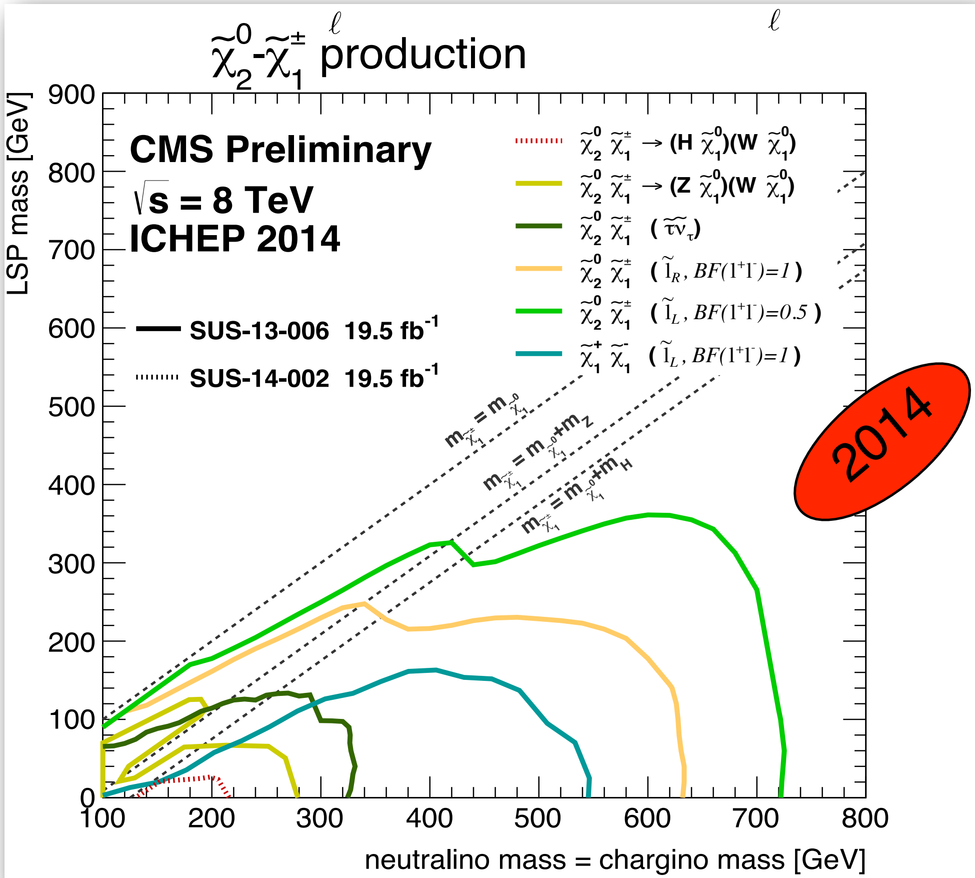
- Mass reach extended by a factor of 2 at 14 TeV, 300 fb^{-1}
- further extended by 20% at 3 ab^{-1}
- If no excess seen at 300 fb^{-1}, can not be seen at 3 ab^{-1}
- 100 TeV pp: increase the reach by a factor of 5.

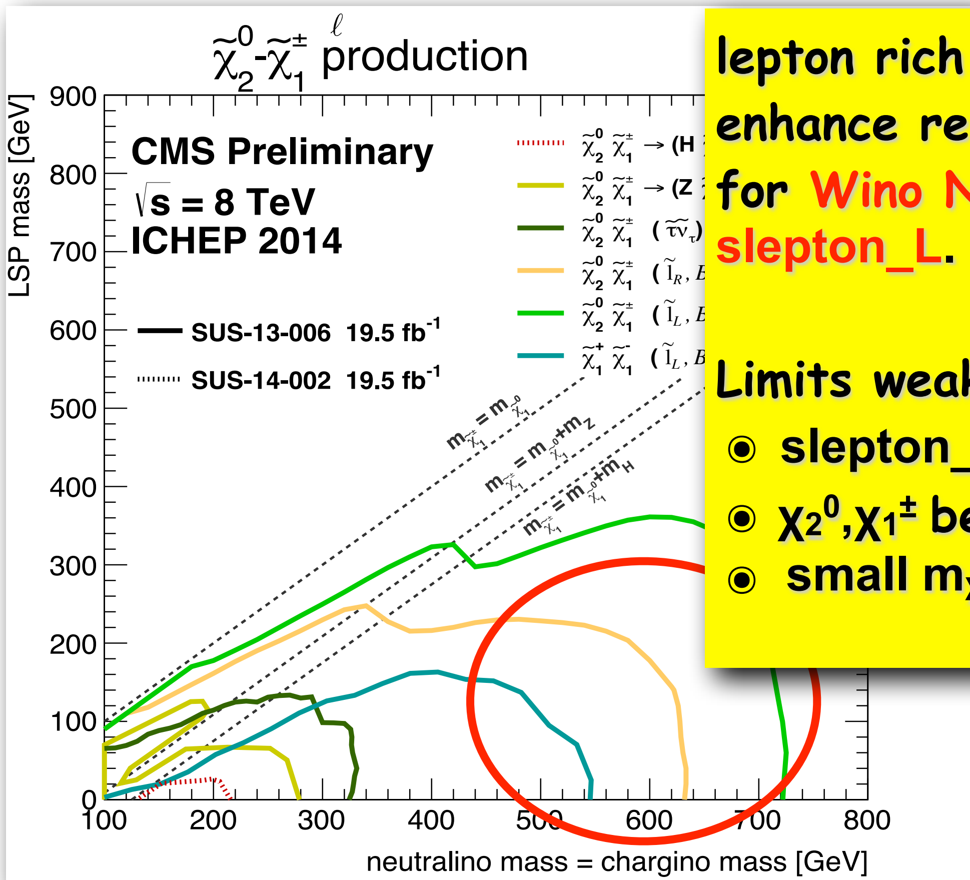
Neutralinos and Charginos

LHC (now): Neutralino/Chargino



S. Su

LHC (now): Neutralino/Chargino

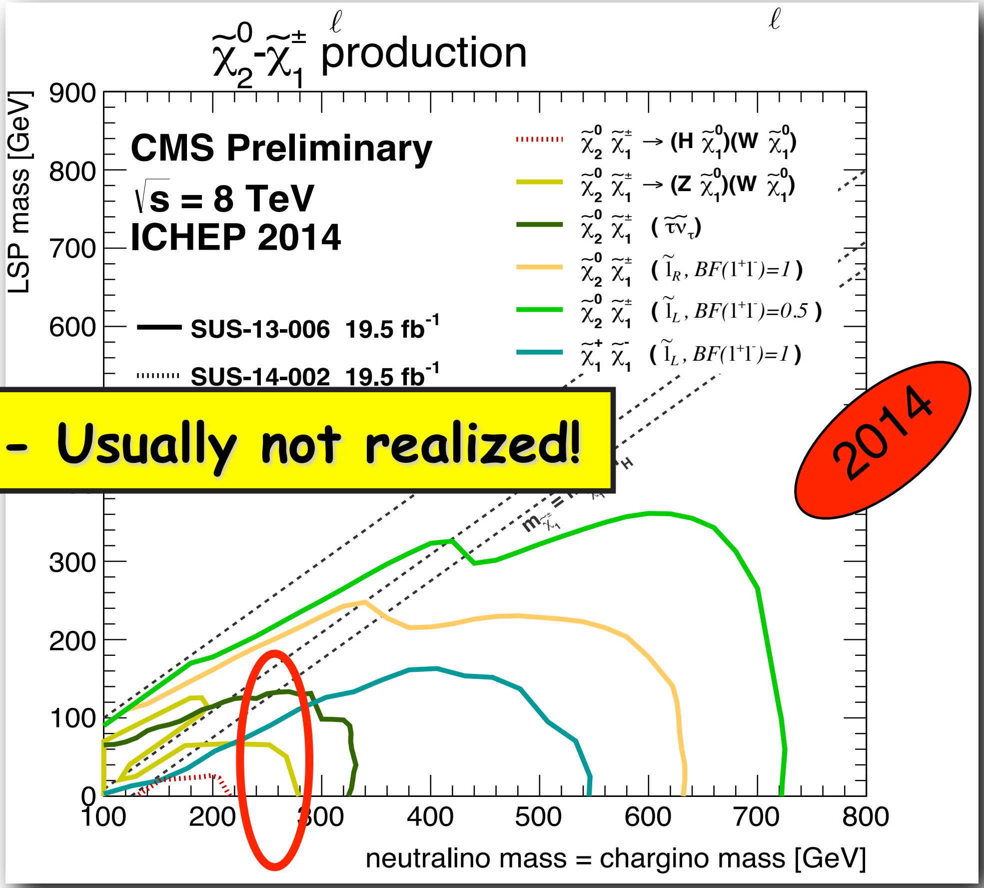


lepton rich final states to enhance reach: only works for Wino NLSP with light slepton_L.

Limits weaker for

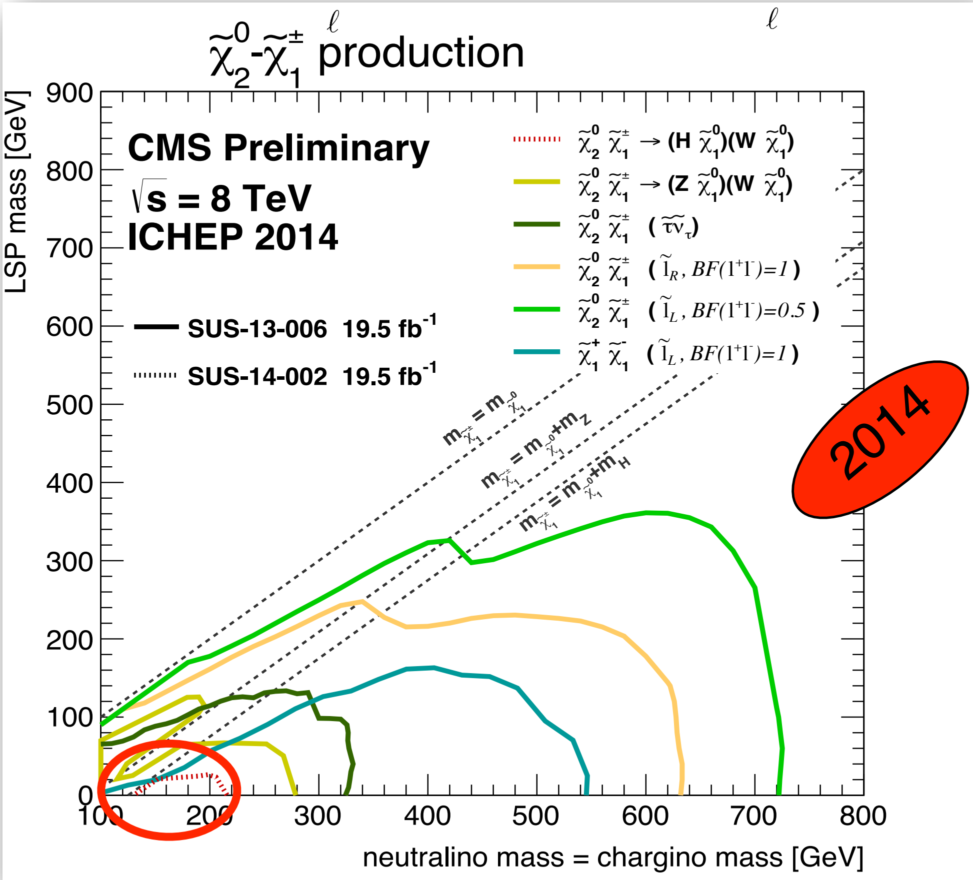
- slepton_L heavy
- $\chi_2^0, \chi_1^{\pm}$ being Higgsinos
- small $m_{\chi 1\pm} - m_{\chi 10}$

LHC (now): Neutralino/Chargino



100% WZ Br -- Usually not realized!

LHC (now): Neutralino/Chargino



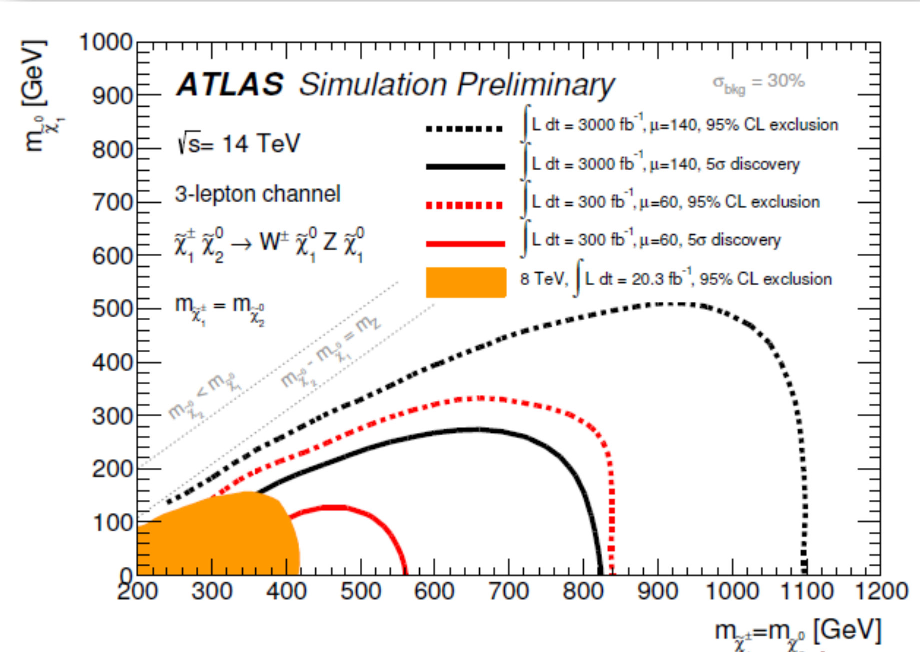
A rich mixture of (W/Z/h)(W/Z/h)+MET final states!

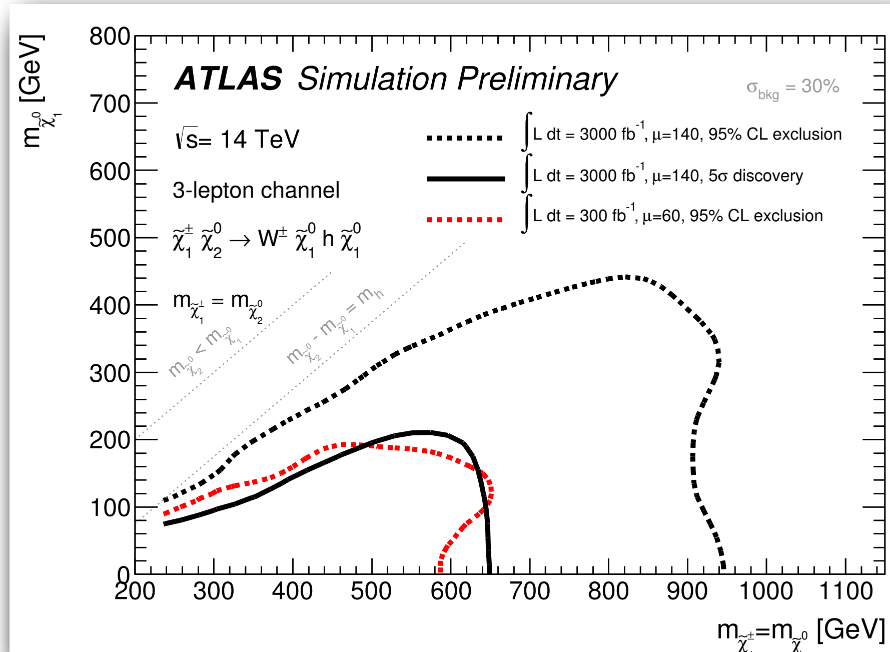
SUSY Electrowinos including Higgs in the final state
Felix Kling

LHC/HL-LHC: Neutralino/Chargino

Prospects of New Physics searches using HL-LHC, Altan Cakir (DESY)

ATLAS-PUB-2014-010





- Mass reach extended by a factor of 2 at 14 TeV, 300 fb^{-1}
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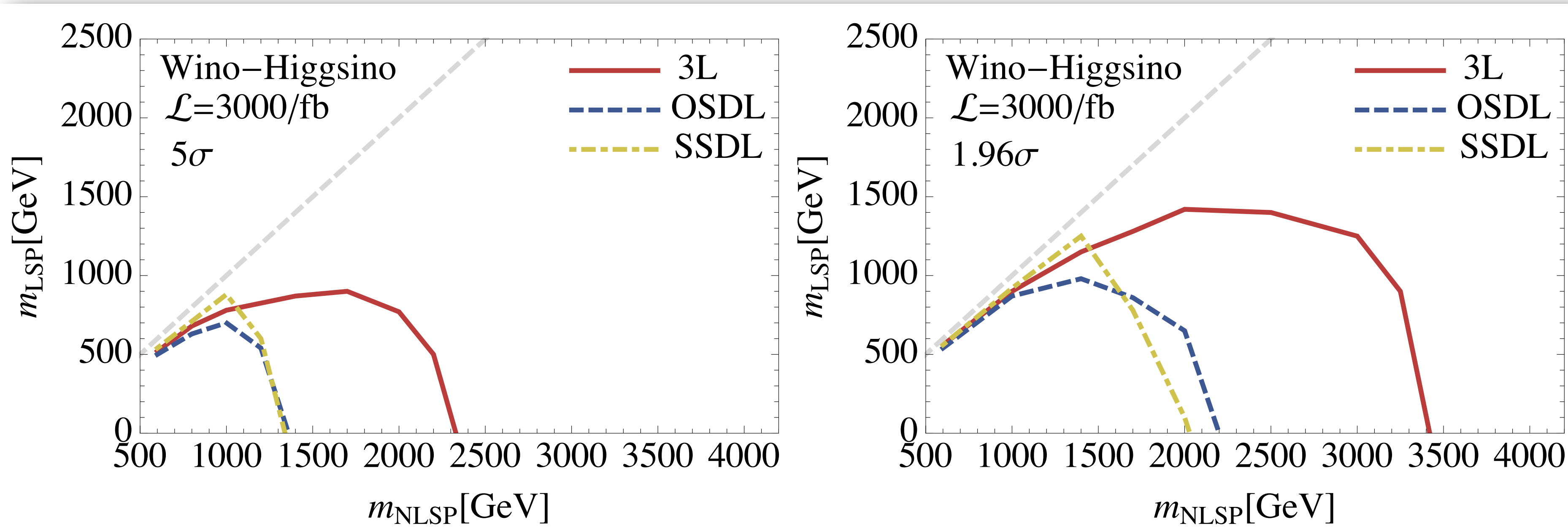
100 TeV pp: Neutralino/Chargino

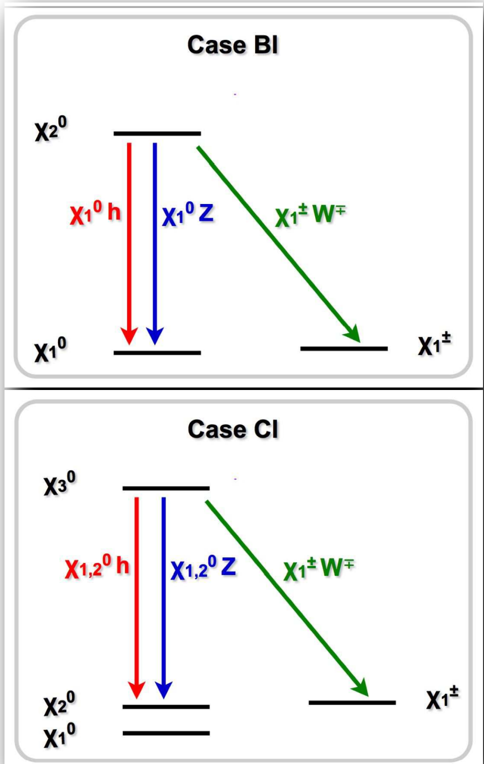
100 TeV pp

Dark Matter, WIMPS or Axions
Prof. Liantao Wang (University of Chicago)



VBF production becomes more important at 100 TeV pp as well.

Neutralino/Chargino: Compressed



NLSP production suppressed.

Compressed spectrum,

nearly degenerate LSP pair productions

ILC: Unique opportunity, MET+Initial State radiation.

SUSY Electrowinos including Higgs in the final state

Felix Kling (University of Arizona)

Dark Matter, WIMPS or Axions

Prof. Liantao Wang (University of Chicago)

Vector boson productions associated with new physics (VBF)

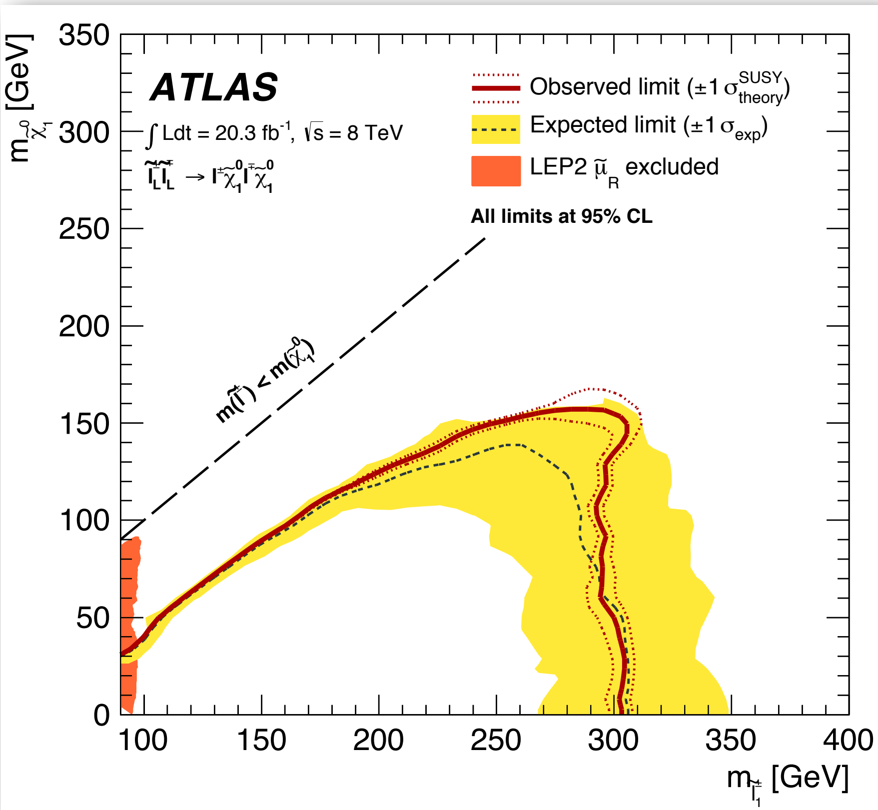
Prof. Bhaskar Dutta (Texas A&M University)

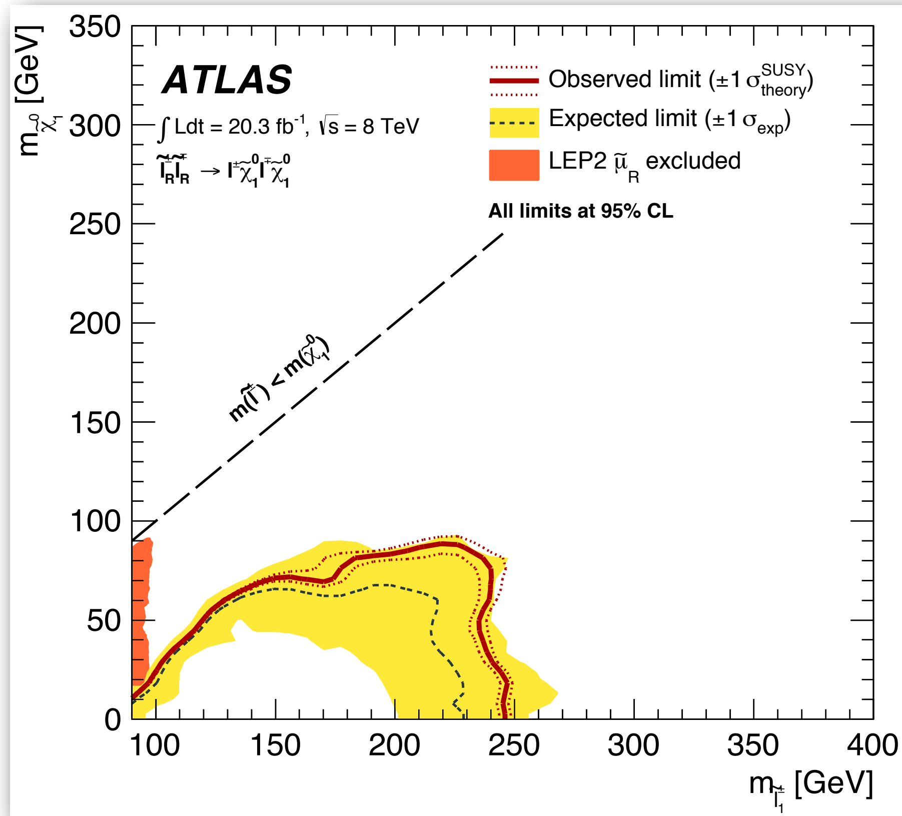
Sleptons

LHC (now): Sleptons

dilepton + MET

ATLAS, 1403.5294

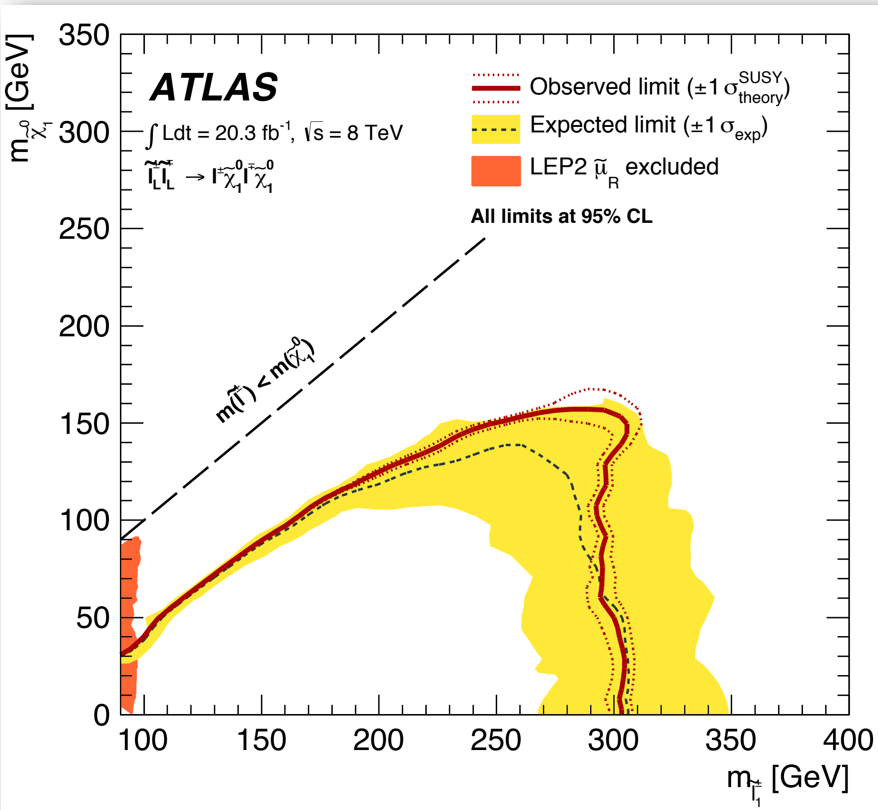


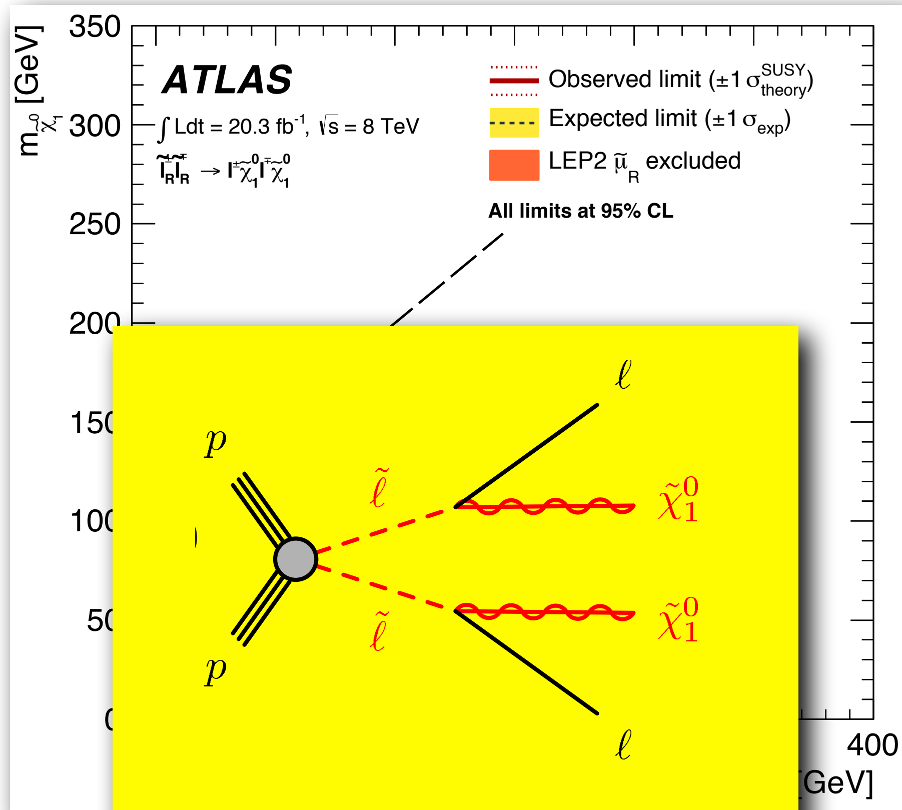


LHC (now): Sleptons

dilepton + MET

ATLAS, 1403.5294

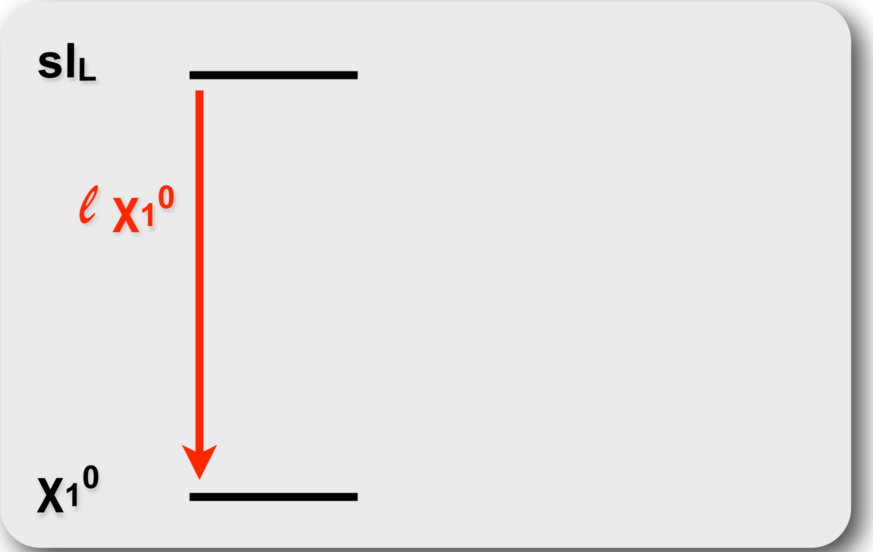




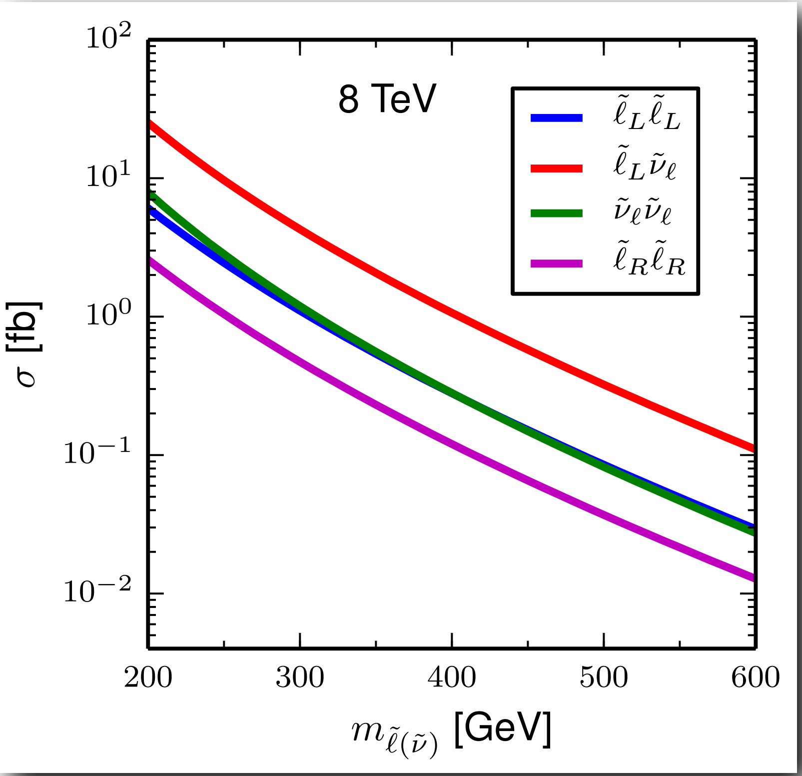
- 100% Br?
- sl sl production?

S. Su

Decay of slepton



Wino-like LSP



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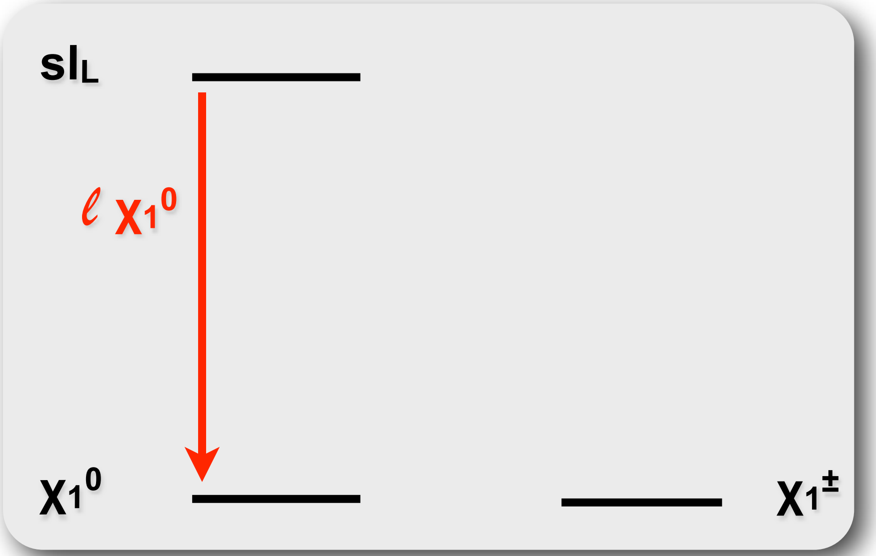
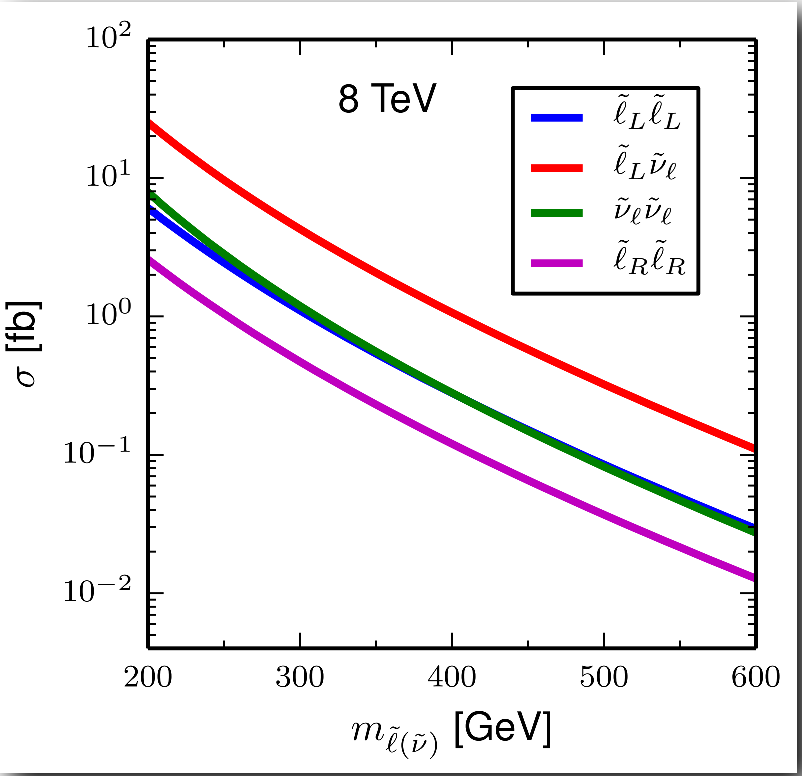


Wino-like LSP



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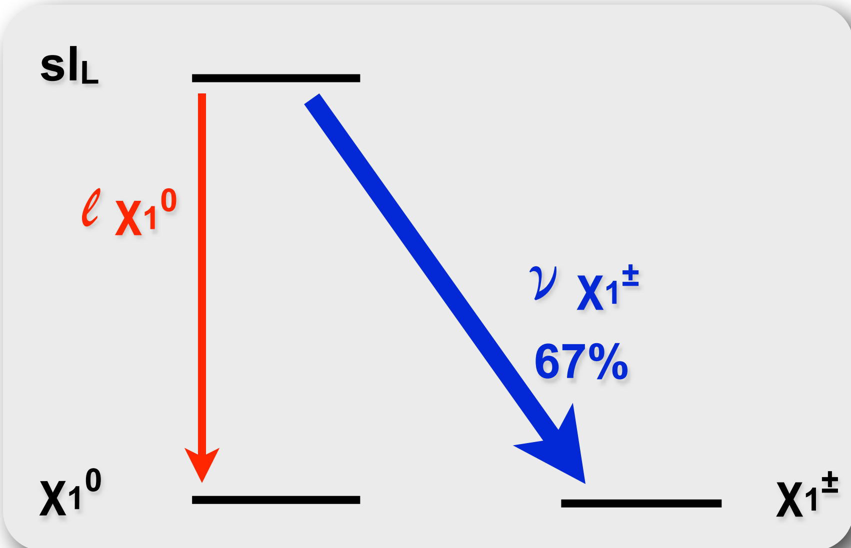

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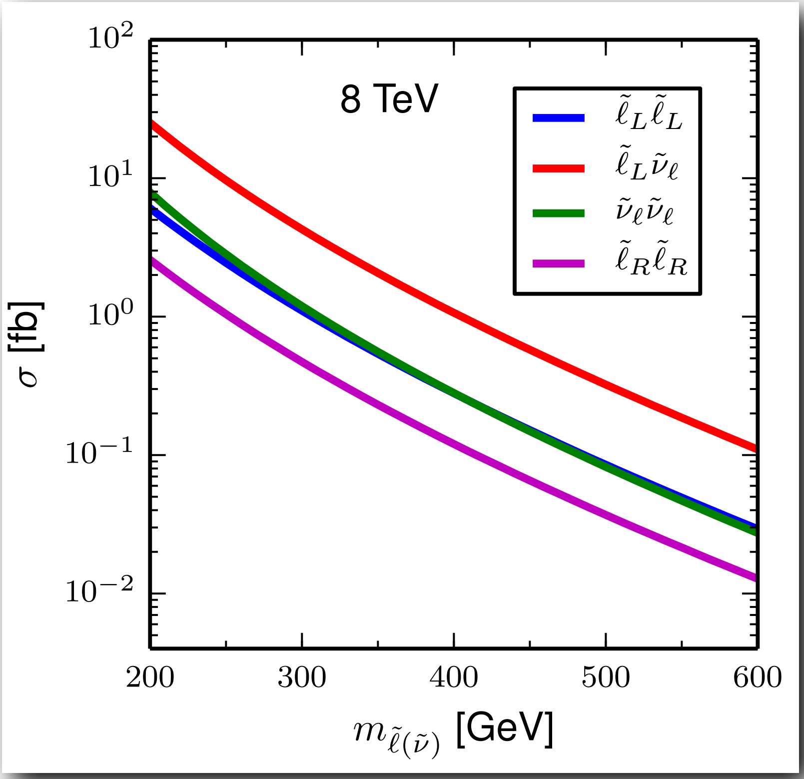

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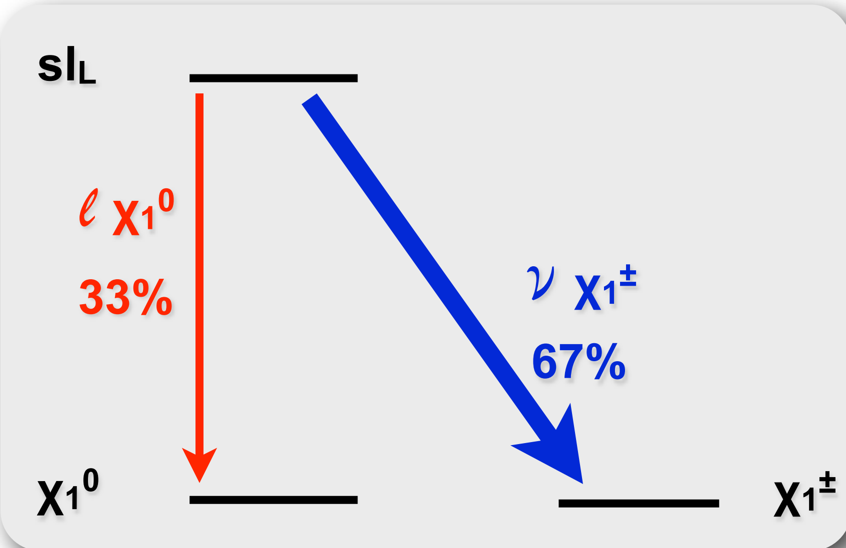
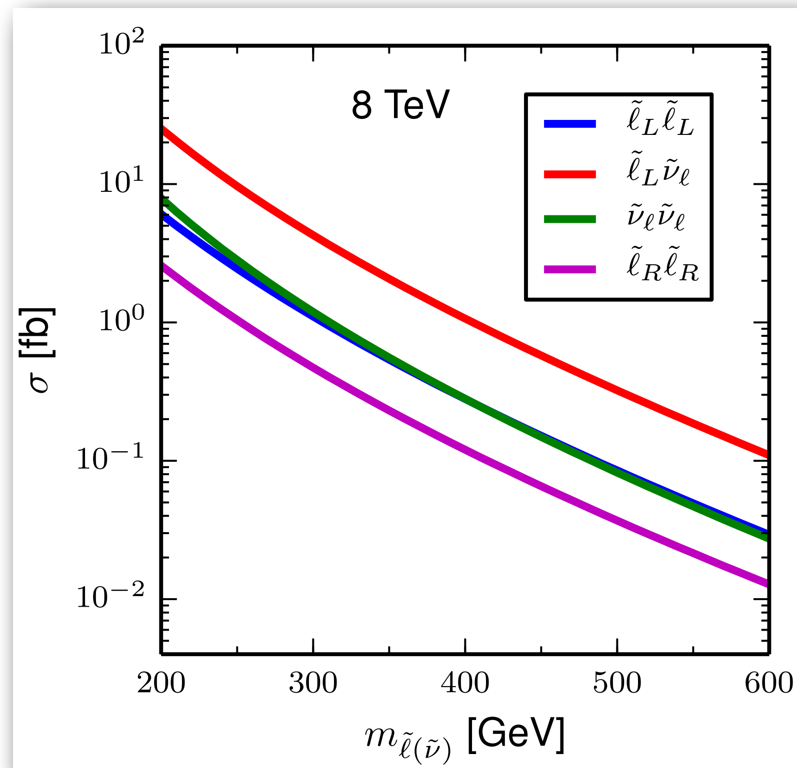
Decay of slepton

Wino-like LSP





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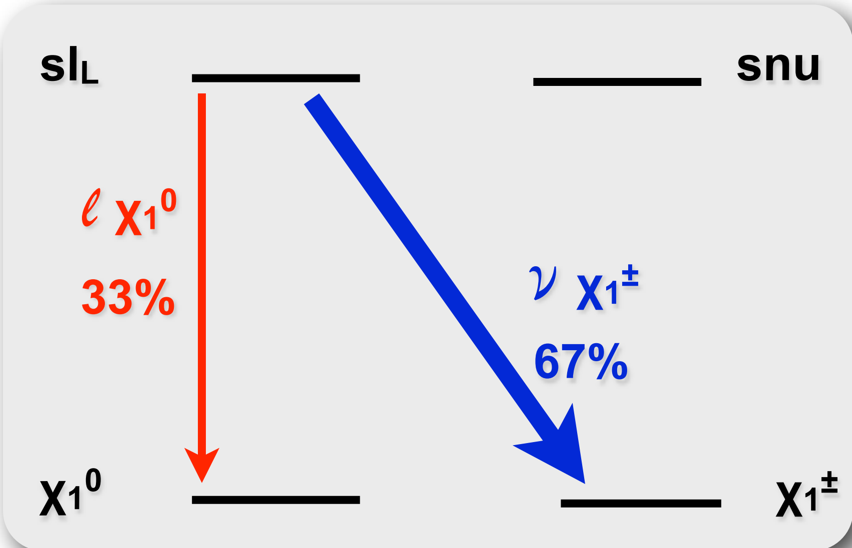
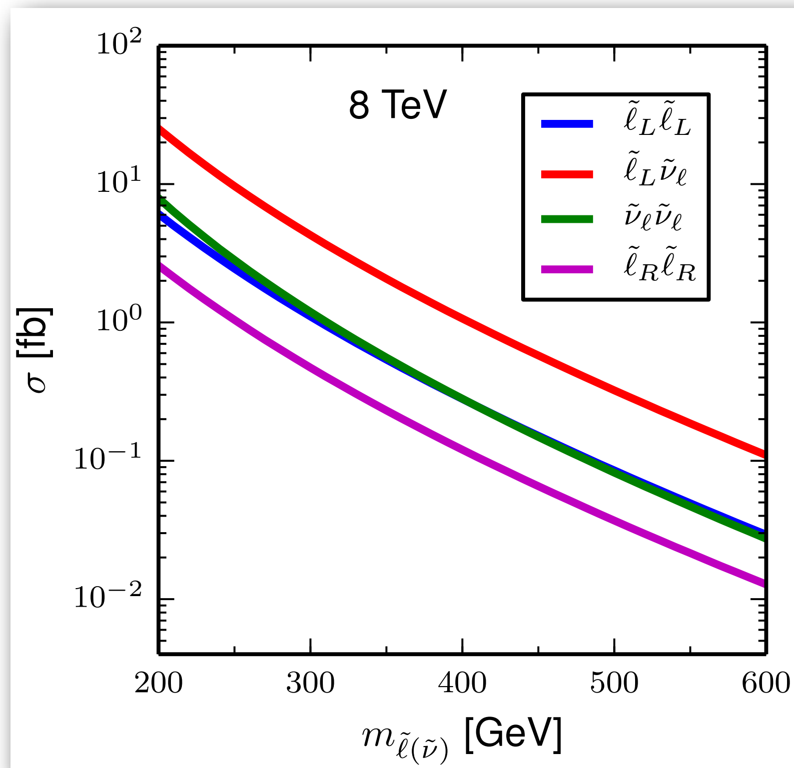


Wino-like LSP



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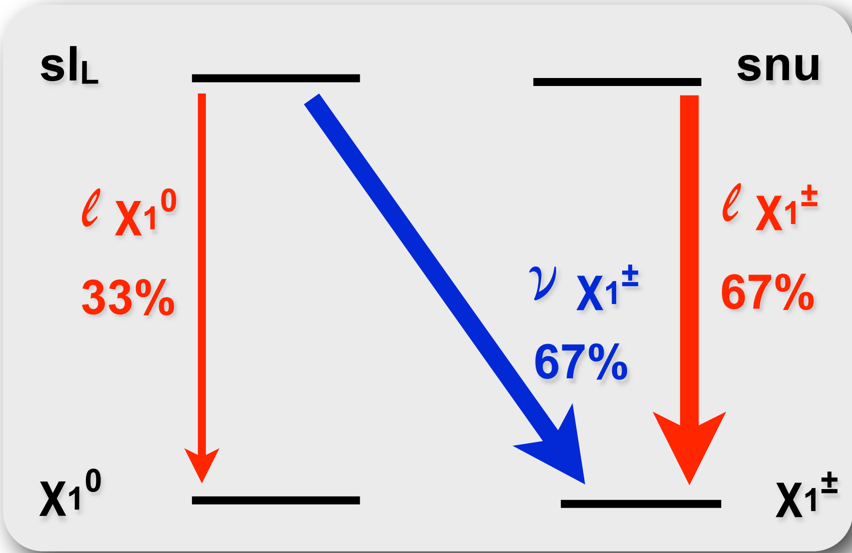
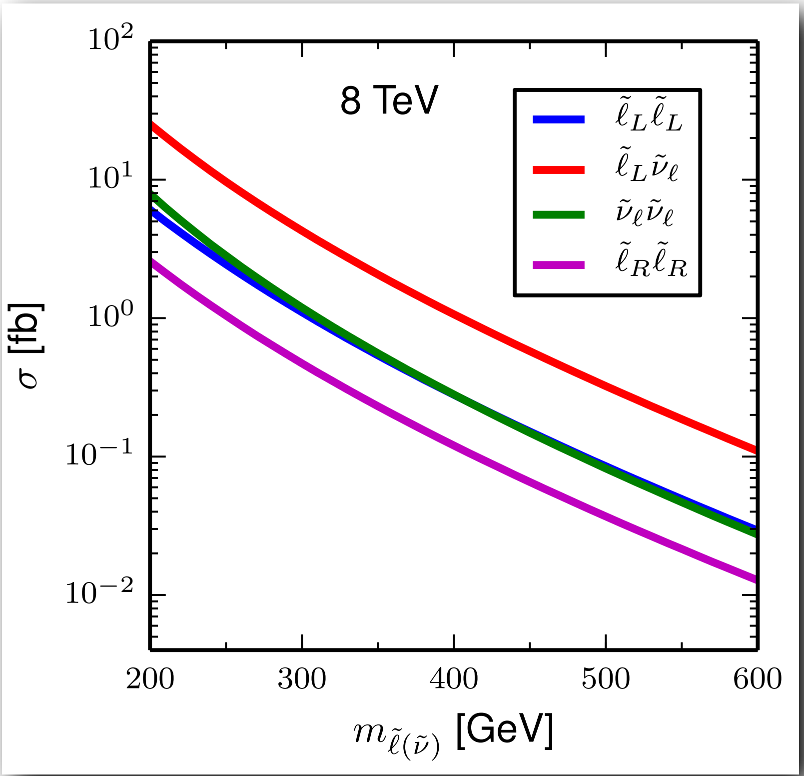
Decay of slepton



Wino-like LSP



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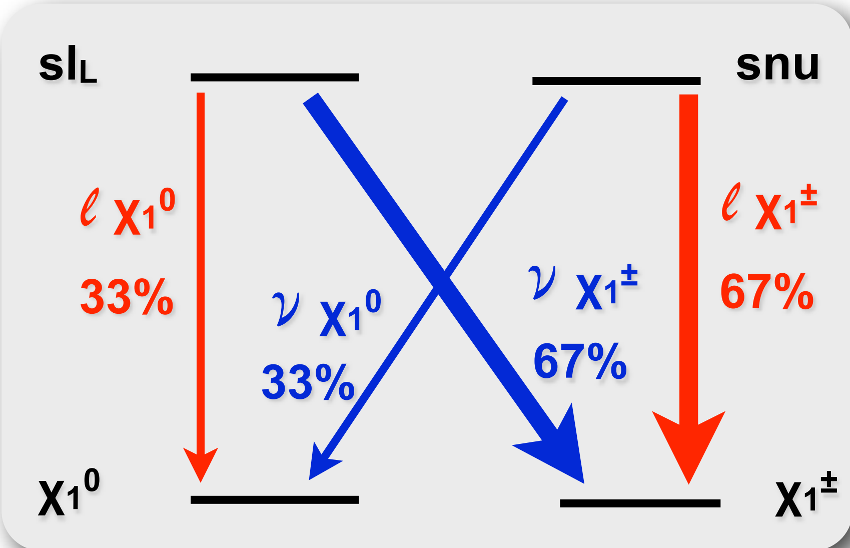

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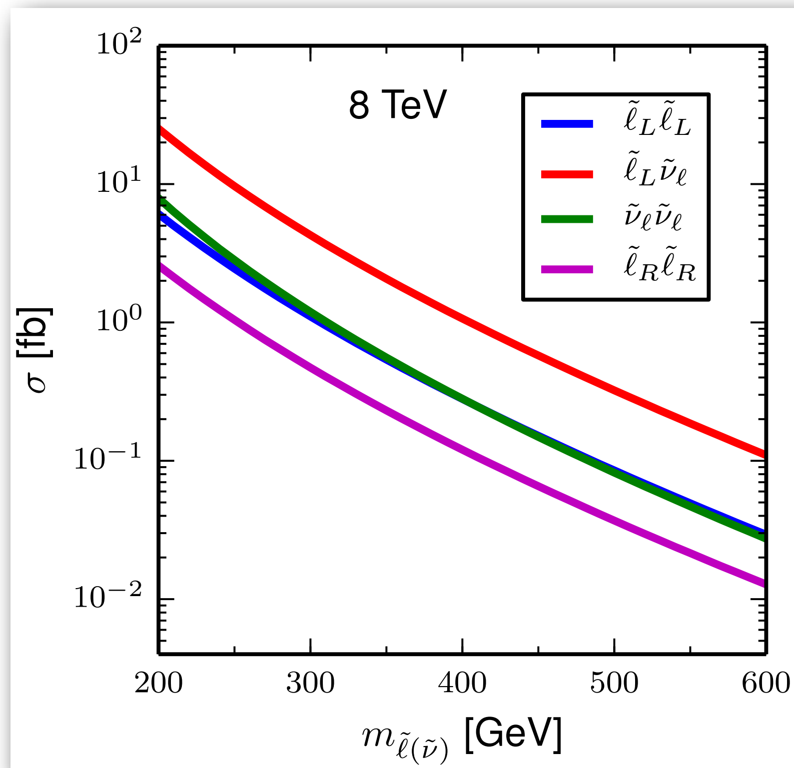

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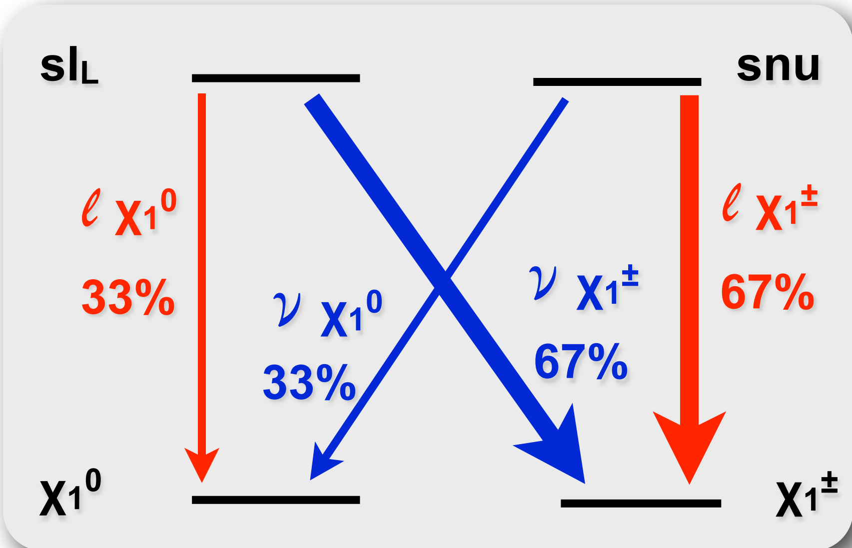
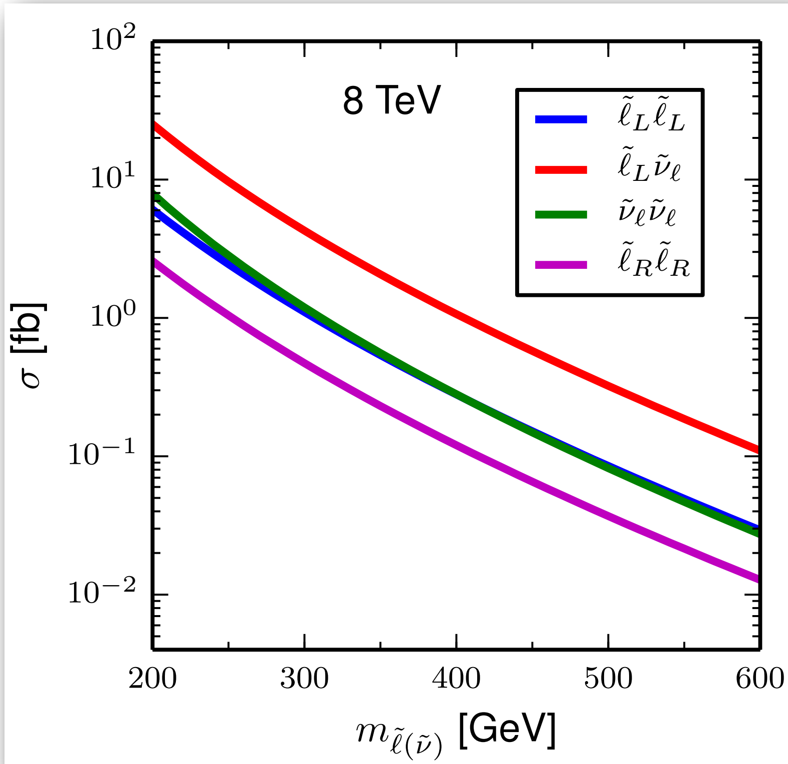
Decay of slepton



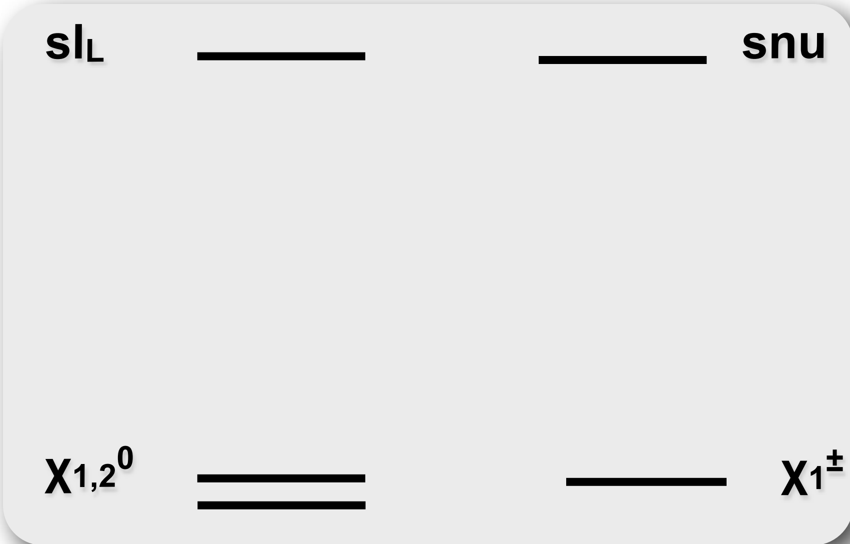
Wino-like LSP

- $sl_L \rightarrow \ell\ \chi_1^0$ Br suppressed
- snu $\rightarrow \ell\ \chi_1^\pm$ contribute
- sl_Lsl_L, sl_Lsnu, snusnu all contribute



S. Su

Higgsino LSP case



Higgsino-like LSP

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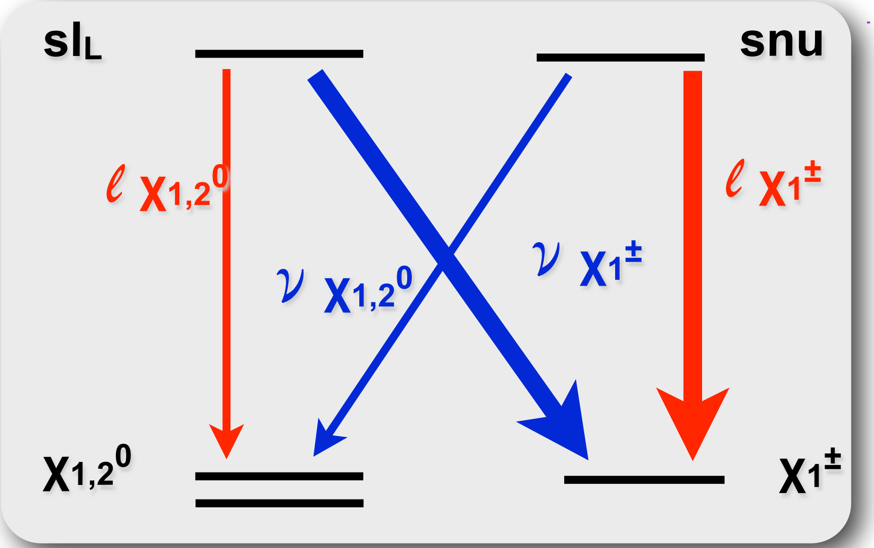

Higgsino-like LSP

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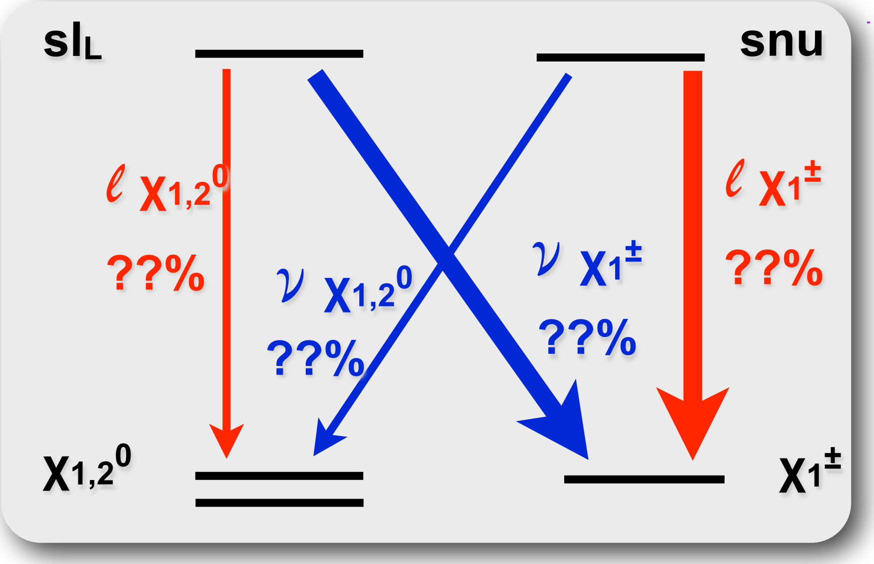

Higgsino-like LSP

S. Su

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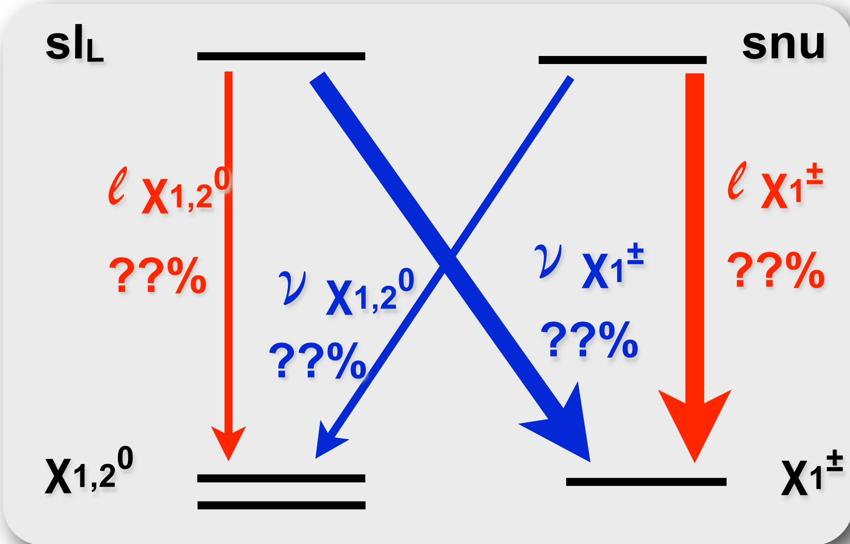
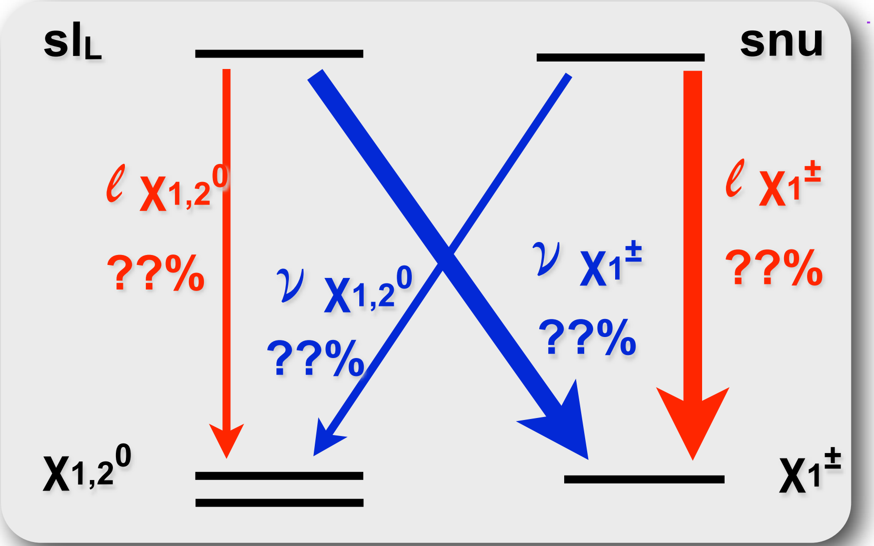


Higgsino-like LSP

- depend on M_1/M_2
- sign of M_1/M_2 matters

Higgsino LSP case



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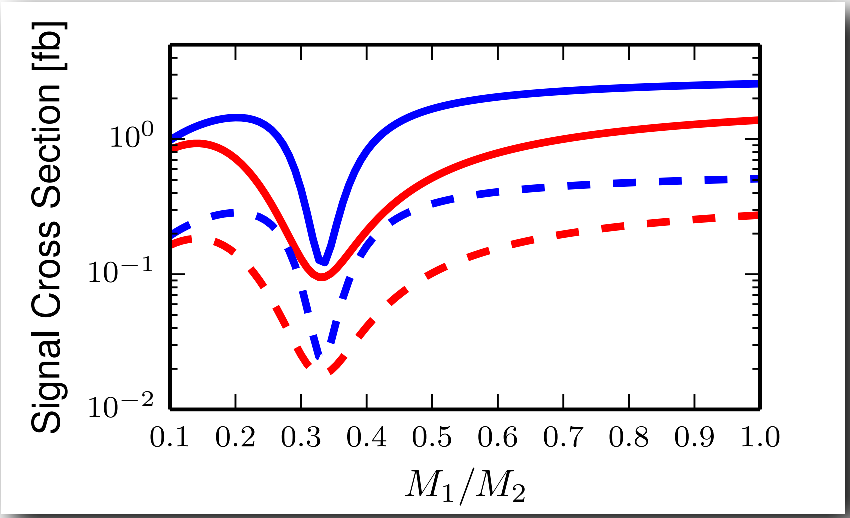

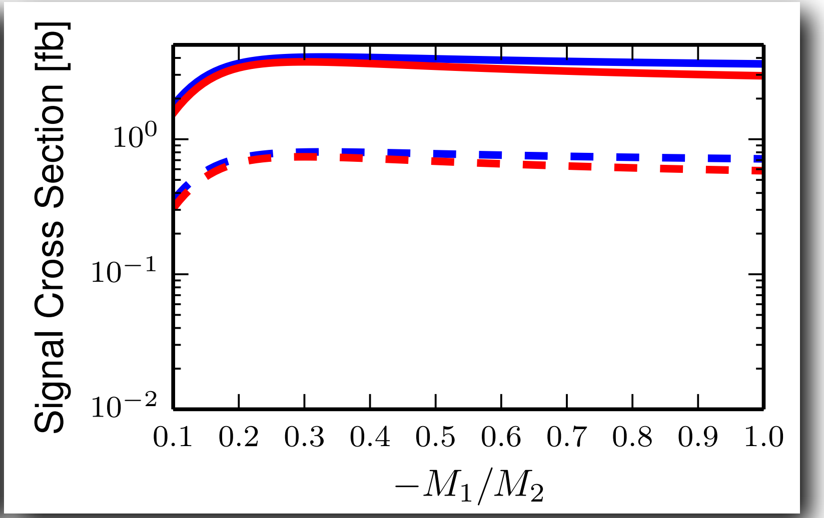

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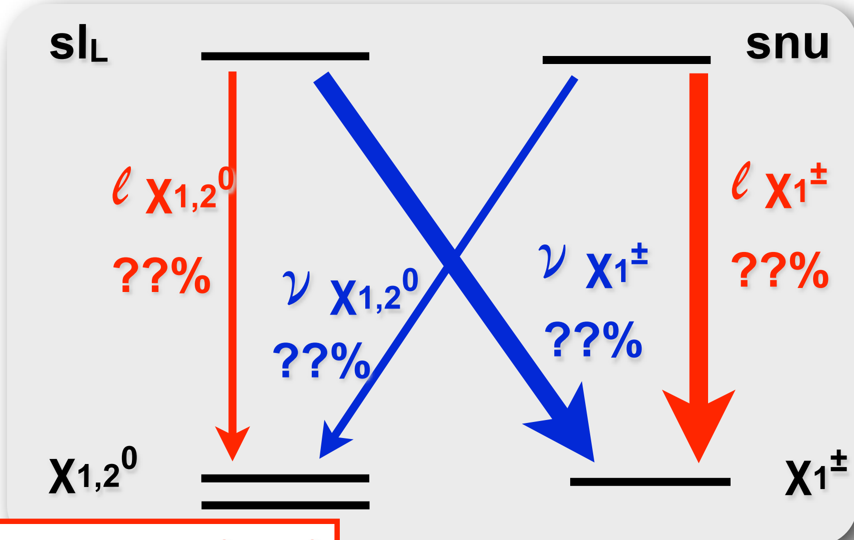

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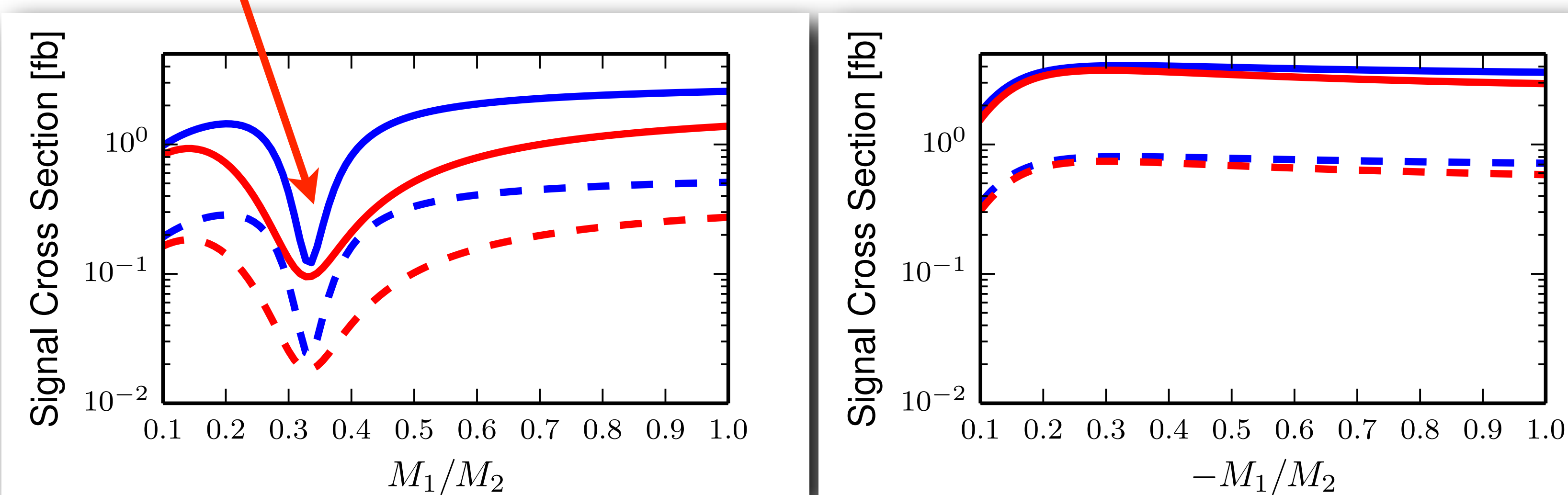
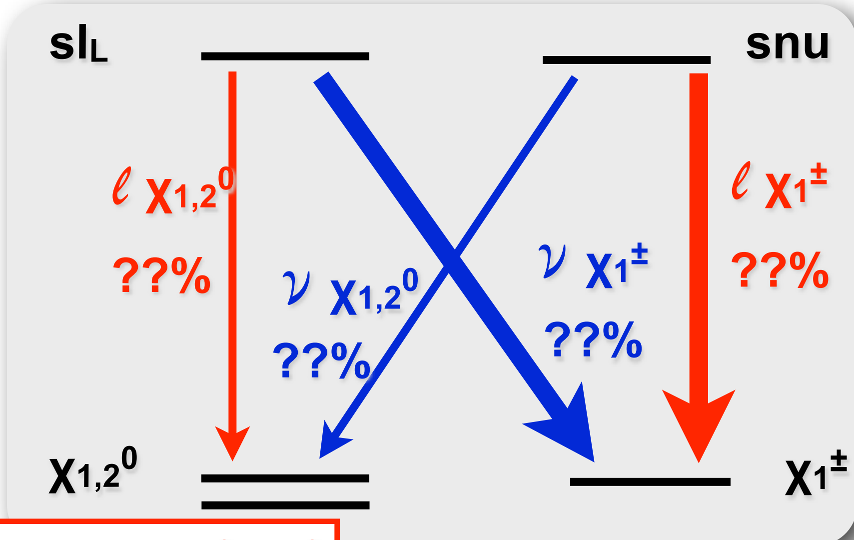
- depend on M_1/M_2
- sign of M_1/M_2 matters

$M_1/M_2 = s_W^2/c_W^2$



Higgsino LSP case



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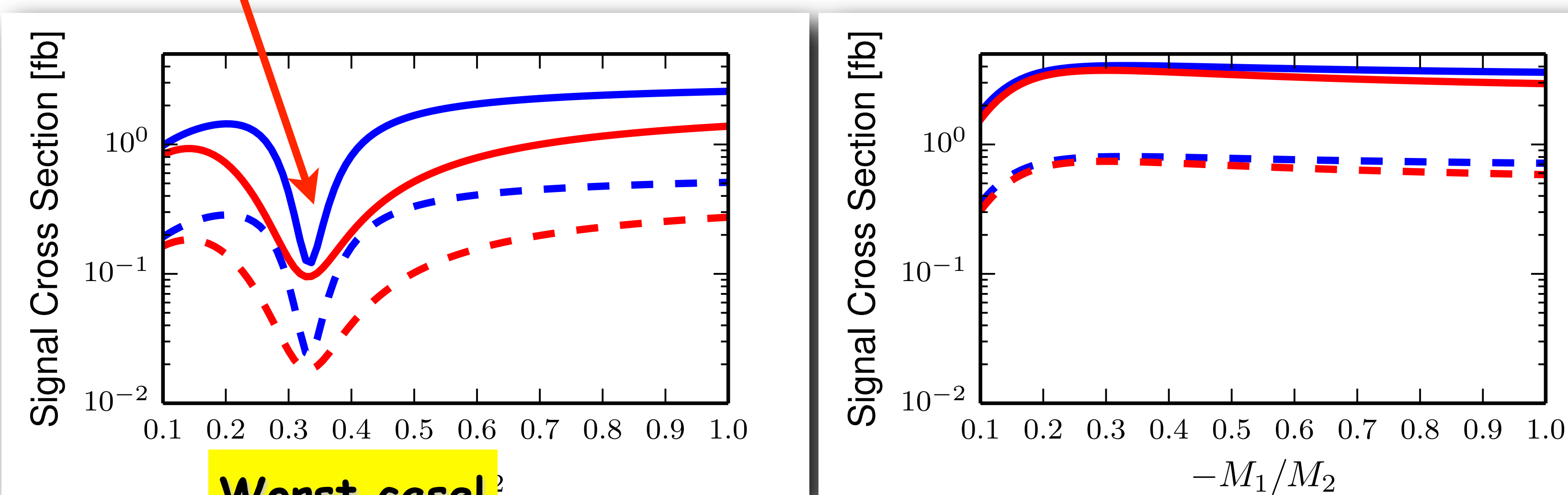
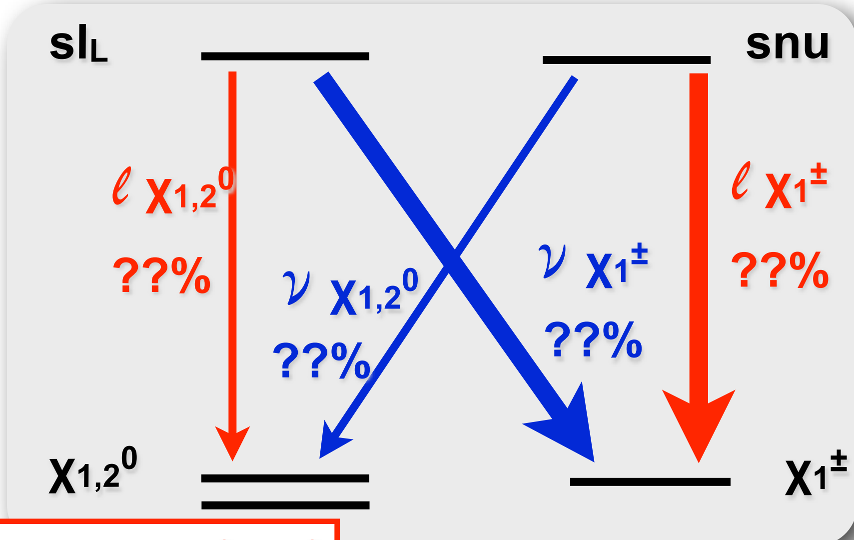


Worst case!

Higgsino LSP case



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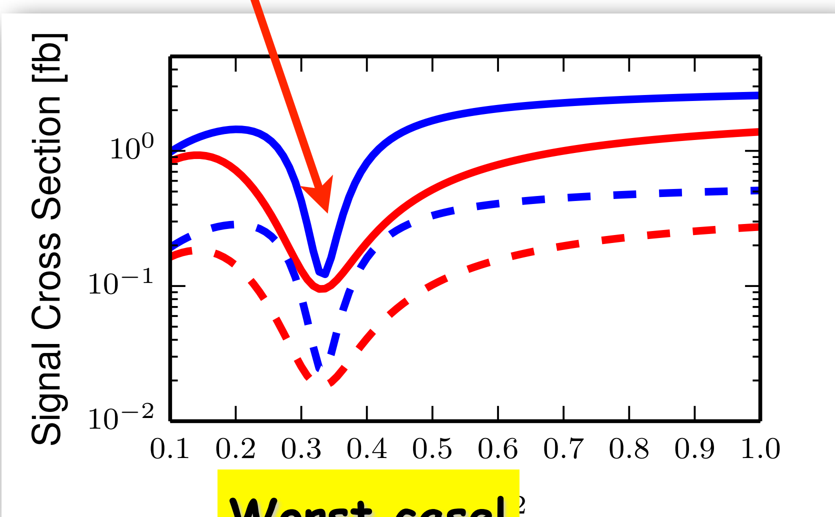
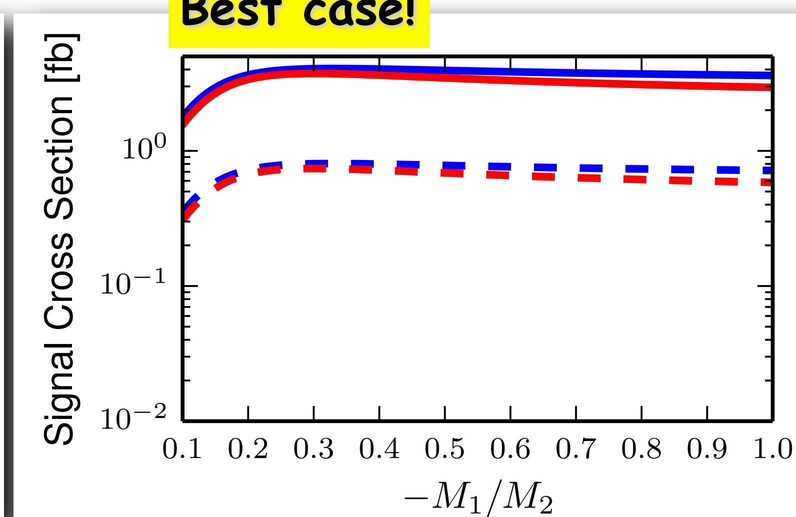
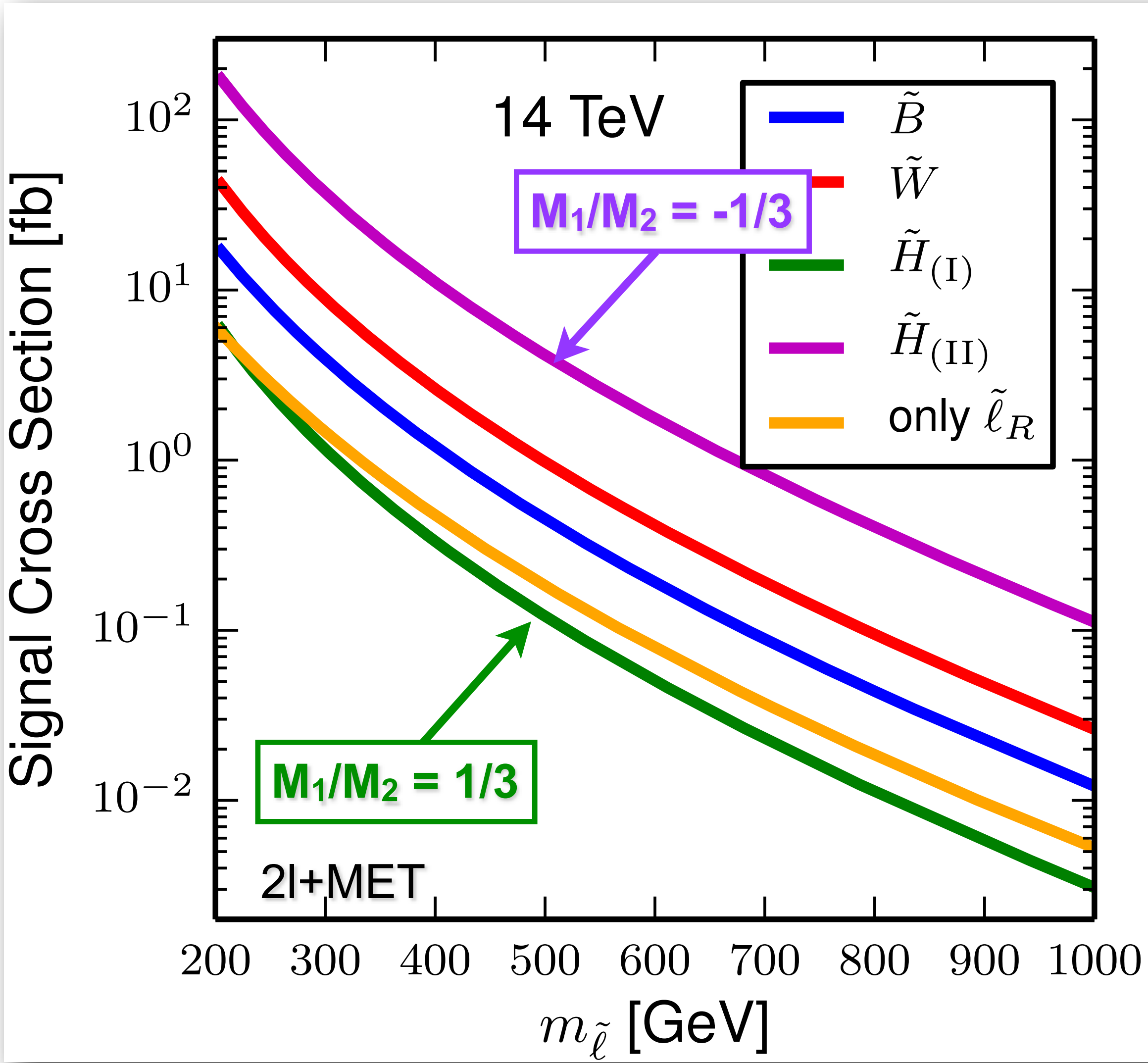


Worst case!

Best case!



2L+MET cross sections



LHC: Sleptons

Eckel, Ramsey-Musolf, Shepherd, Su (2014)